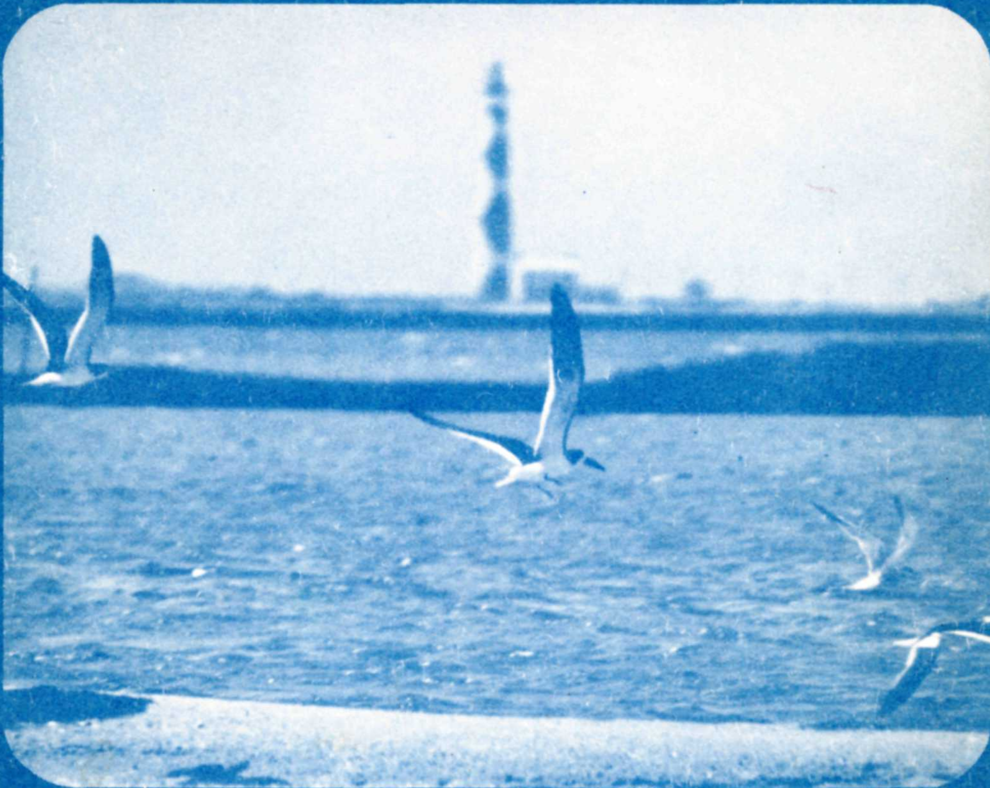


Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina

Barrier Island Ecology of Cape Lookout National Seashore and Vicinity, North Carolina

PAUL J. GODFREY
National Park Service Cooperative Research Unit
University of Massachusetts, Amherst

MELINDA M. GODFREY
Institute for Man and Environment
University of Massachusetts, Amherst

National Park Service Scientific Monograph Series • Number Nine • 1976

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $2.40

Stock No. 024-005-00670-2

As the Nation's principal conservation agency, the Department of the Interior has basic responsibility for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources." The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

This publication is one in a series of research studies devoted to special topics which have been explored in connection with the various areas in the National Park System. It is printed at the Government Printing Office and may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

Library of Congress Cataloging in Publication Data

Godfrey, Paul J.
Barrier island ecology of Cape Lookout National Seashore and vicinity, North Carolina.

(National Park Service scientific monograph series; no. 9)
Bibliography: p.
1. Seashore ecology—North Carolina—Cape Hatteras National Sea Shore. 2. Cape Hatteras National Sea Shore, N.C. I. Godfrey, Melinda M., joint author. II. Title. III. Series: United States. National Park Service. Scientific monograph series; no. 9.
QH105.N8G6 574.5'26 76-608314

Acknowledgments

The research for this paper was supported by the Office of the Chief Scientist, National Park Service and the Cape Lookout National Seashore. Certain photographic materials were supplied by Cape Hatteras National Seashore. We thank the superintendents of Cape Lookout National Seashore who encouraged our work and cooperated fully: Mr. Thomas Morse, who first suggested the research projects, Mr. Daniel Davis, Mr. Robert Barbee, and Mr. Preston Riddel. We especially wish to acknowledge the help of Mrs. Amanda Gillikin, Administrative Secretary for Cape Lookout National Seashore, who handled most of the fiscal aspects of the project since its beginning in 1968 and learned to tolerate the strange ways of biologists. Ms. Cheryl McCaffrey of the University of Massachusetts provided invaluable assistance beyond the call of duty in preparing the photographic plates. We thank the Chief Scientist and his staff for providing the support funds for most of the work. We also thank the personnel at the U.S. Coast Guard's Cape Lookout Station for their assistance and cooperation. Mr. and Mrs. Rod Meyers, owners of Cape Lookout Marina, provided services beyond those of pure business and we appreciate their help.

Finally, we wish to acknowledge our colleagues and former professors at Duke University for their helpful comments during the course of this research, and especially Dr. I. E. Gray who first brought the problems of barrier-island development to our attention.

PAUL J. GODFREY

MELINDA M. GODFREY

Contents

Figures

1
Introduction

Most people think of the National Park Service as the guardian of the spectacular West, plus a handful of outstanding eastern sites. In recent years, however, the service has expanded rapidly into the management of coastal lands in the form of National Seashores. These ventures are quite different from the traditional objectives of the National Park Service since the seashores are classed as "recreation areas"; recreation is the main concern, with preservation of natural features a secondary objective.

Cape Hatteras was the pioneer National Seashore, followed on the East Coast by Cape Cod, Fire Island, Assateague, Cape Lookout, Padre Island, and most recently Gulf Islands, with further projects underway. Altogether, the National Park Service will control about 400 miles of Atlantic and Gulf shoreline and 425,500 acres of beaches, dunes, dramatic sea cliffs, maritime forests, fresh ponds and marshes, and estuaries. Since the seashores range from Cape Cod in the north to Padre Island near the Texas-Mexico border, these critical coastal habitats can be found in fascinating variety.

One main impetus for the National Seashore program has been the need to preserve some unspoiled shoreline within easy reach of the urban public with its increasing appetite for recreation. Another principal motive has been the specter of beach erosion. Political pressure from groups interested in these two aspects has a great influence on the direction that National Seashore development takes. As examples, the building of roads and bridges for easy access has often been stipulated in the seashores' enabling legislation; and when seashores are set up, the National Park Service is almost always given a mandate to control erosion and flood damage through cooperative efforts with the U.S. Army Corps of Engineers. Even though the National Seashores are protected from Coney Island-type development, they still face other, almost as dramatic, alterations in the name of recreation and erosion control.

The seashore program has grown more rapidly than has our

knowledge of how to reconcile the guidelines of the seashores' establishment with broader National Park Service ideals of natural resource preservation. Planners find coastal data spotty at best. The scientific information that has been built into seashore management plans has often been that of the U.S. Army Corps of Engineers, which concerns itself almost solely with controlling beach erosion and storm flooding. Sometimes the plans have been drawn up so quickly that planners have had no time to search the literature for better information, and in altogether too many cases the scientific community has simply failed to make adequate data available. Coastal scientists obviously have an important responsibility to meet in advising seashore managers. Fortunately, recent years have seen an improvement in both the quantity and quality of coastal research, with biologists and geologists learning to see the maritime environment as an integrated whole. Nearly every seashore now has in progress at least one study designed to come up with the information so badly needed by managers.

Even when the manager is supplied with data, his troubles are not over; more and more, the patterns of natural change which emerge are at variance with political and economic interests. When a restless ocean rearranges a shoreline that cottage and motel owners expect to remain static, the National Park Service, which frequently has ownership of the beach front such as at Cape Hatteras, finds itself quite literally trapped "between the devil and the deep blue sea."

TRADITIONAL MANAGEMENT APPROACHES

The basic geological and ecological research that has been done at the land-sea interface has often simply been ignored, or else it has not been applicable to management problems. Geologists have tended to think mainly about sand movement. Coastal botanists have been content just to list species; ecologists have usually been interested in the adaptations of biological systems to maritime influences such as salt spray, moving sand, and tidal flooding. Most studies have been so compartmentalized that the interrelationships of the total coastal ecosystem have been obscured. Much has been made of what the "natural ecology" of the shoreline, particularly barrier islands, is supposed to be. Many have assumed that maritime woodland represents this "natural ecology;" an island lacking such a woodland has been "damaged" and must be restored to its "original, pristine" condition by engineering works. Such an approach to "conservation" has actually led to projects that involve pumping sand out of estuaries and salt marshes for dune lines and beach fill. This leaves us with the ultimate absurdity of

destroying an existing "natural ecology" in order to restore a "natural ecology" that could not possibly survive under prevailing conditions and indeed may never have existed at all.

The main goal of a considerable part of past coastal research has been to find mechanical or biological ways to combat beach erosion. Vast sums have been spent on engineering studies, and on sea walls, dikes, man-made dunes, jetties, groins, beach fill, and even plastic bags full of sand, in the vain hope of holding down the retreating beaches. Most of these efforts were demanded by commercial interests trying to protect businesses, private landowners whose cottages were about to fall into the sea, and even by National Seashores in danger of losing visitor-use facilities and roads. There is a widespread myth that the barrier islands are in grave danger of disappearing unless something is done. The U.S. Army Corps of Engineers (1971) has just completed an erosion study of United States shorelines and has called for $1.8 billion to combat recession along 2700 miles of coast. Ironically, these projects often either make natural erosion worse or even start new erosion; ways must then be found to undo the damage.

Whether a stable dune line is built with sand fences and beach grass, or by dredges, bulldozers, and beach grass, the results are the same: a wall against the sea. The idea is to get that dune line up as high as possible, and not to allow any messy natural processes such as the wind blowing the sand around, the ocean overtopping dunes, or the beach continuing to retreat. In other words, total artificial control of the coastline is attempted. The trouble is, it doesn't work.

PRESENT RESEARCH

Soon after Cape Lookout National Seashore in North Carolina was authorized, the National Park Service instituted a research project designed to find ways to avoid some of the management problems experienced at nearby Cape Hatteras National Seashore. These two seashores are on the same barrier-island chain but are separated by Ocracoke Inlet (Fig. 1). The separation has given us an opportunity to compare a heavily developed seashore with one which has hardly been touched. The Cape Lookout islands have only a few fishing camps, while the Cape Hatteras area has paved roads, bridges, towns, visitors' facilities, and commercial operations, plus all the engineering works designed to protect such things.

Our ecological work at Cape Lookout began in 1968, and we will report here some of the ways in which we observed that barrier islands and their ecosystems seem to be adapted to the sea. We have tried to tie

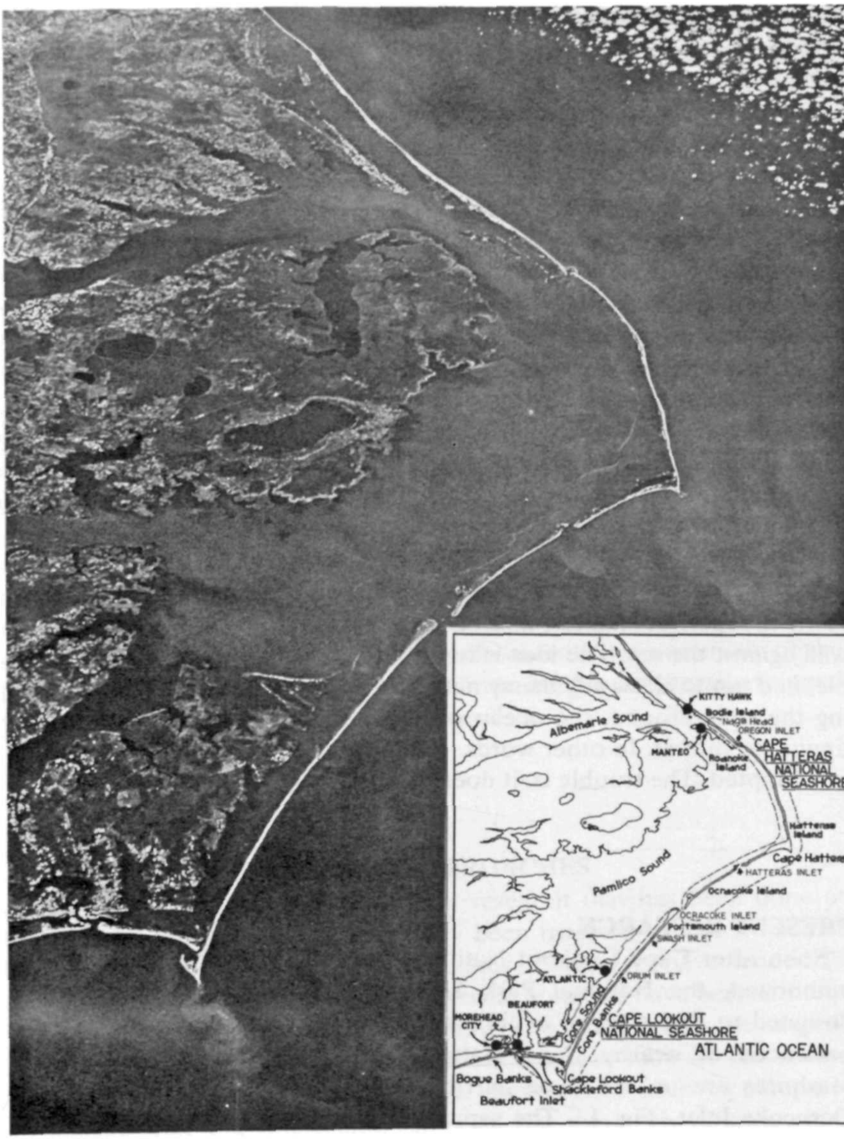


Fig. 1. Apollo 9 photograph of North Carolina Outer Banks, showing Cape Lookout and Cape Hatteras National Seashores, taken from an altitude of 120 miles on 12 March 1969. The linear distance from the top of the photograph to Cape Lookout is about 150 miles (241 km). (*Photo by* NASA)

together some of the factors which influence the whole island system, from beach to estuary. As yet we have only scratched the surface, but we look forward to being able to fill some of the gaps.

A partial listing of other research projects underway on the Outer Banks follows. Dr. Robert Dolan of the University of Virginia is doing geological research at Cape Hatteras and Cape Lookout, and various projects are underway at other seashores. Recent geological studies on the Outer Banks led to dissertations for Dr. J. W. Pierce (1964) and Dr. J. J. Fisher (1967). Fisher also studied relic inlets on the Outer Banks for a Masters thesis (1962). Doctors Riggs and O'Connor of East Carolina University have been conducting geological and biological studies of the northern Outer Banks. Paul Hosier of Duke University is now completing a Ph.D. dissertation on the ecological effects of overwash at Cape Lookout National Seashore; his work expands some of our preliminary observations described here. Au (1969) described the vegetation of Shackleford Banks within Cape Lookout National Seashore. Scientists from North Carolina State University (Doctors A. W. Cooper, W. W. Woodhouse, E. Seneca, J. Langfelder) are working on various projects along the Outer Banks such as dune stabilization, the ecology of dune strand plants, stabilizing dredge spoil with marsh grass, rates of beach recession, and so forth.

GENERAL FEATURES OF THE COASTAL ENVIRONMENT

We will restrict our observations to the patterns we see on the Outer Banks, but these patterns repeat themselves, at least in general, all along the East Coast. Few environments are in such a state of flux as a coastline which is constantly being reworked by sea, wind, and water. Only a few remarkable terrestrial organisms can stand up to the rigors of salt spray, sea-water flooding, water stress, and moving sand. Where the ecological hazards are most severe, species diversity is very low; sometimes a whole community is dominated by one or two hardy vascular plants.

The controlling environmental force, of course, is the ocean; its storms and its changing level have combined over time to determine the seashore's primary characteristics. Hurricanes and winter northeasters can be expected to drive high water over the beach annually. The storms seem to come in cycles, with relatively calm periods followed by a great deal of storm activity. At least 149 hurricanes affected the North Carolina coast between 1585 and 1966 (Carney and Hardy 1967). Figure 2 shows the storm tracks of September hurricanes in the western Atlantic over a 60-year period (Cry 1965).

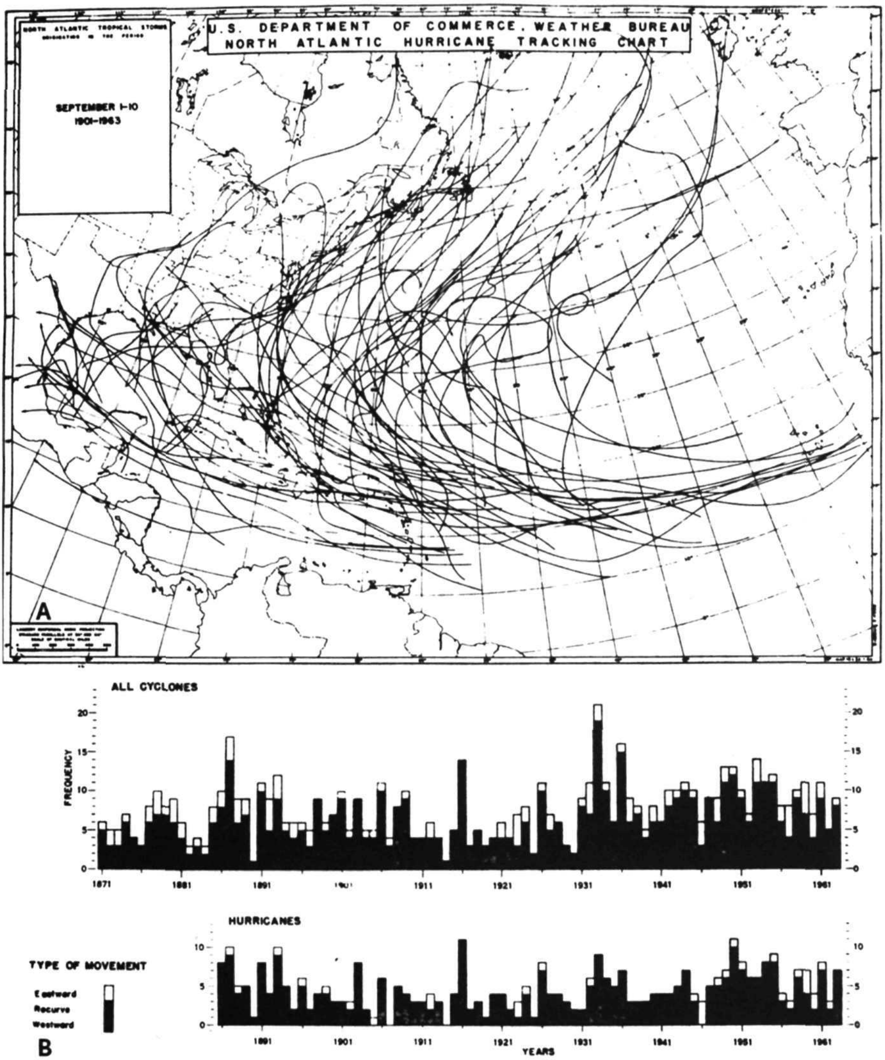


Fig. 2. (*A*) Hurricane tracks during the first 10 days of September (time of maximum storm activity) for a 62-year period. (*B*) Total annual frequency of North Atlantic tropical cyclones (1871–1963) and hurricanes (1886–1963). Note the general pattern of movement westward, then recurving north and northeastward up the U.S. East Coast. The Outer Banks are an area of storm concentration, almost a focal point. (*From* Cry 1965)

All through the history of the earth the land-sea interface has been in a state of change. Our present shorelines are the result of the post-Pleistocene sea-level rise, which covered much of what was once land. Isostatic variations have been superimposed upon the general eustatic sea-level change, so that the apparent effect of the increasing amount of water in the sea varies along the coast depending on whether the local land is rising or subsiding. Although coastal geologists argue about the exact pattern of sea-level changes since the last Ice Age, most agree that the ocean level reached a low of about −130 m from its present position at the height of the Wisconsin glaciation, and has risen ever since. Evidence also shows that the sea rose faster prior to about 5000 or 6000 years ago than it is rising now (Fig. 3). Today, along the southeastern coast of the United States, this rise relative to the land surface has been about 25 cm per century. Recent estimates suggest a rise of 8 cm in the past decade (Hicks 1971). The rate also varies along the East Coast; in some places the sea level seems to be at a relative standstill. However, the worldwide trend of rising sea level has resulted in general erosion and retreat of shorelines (Hoyt 1967).

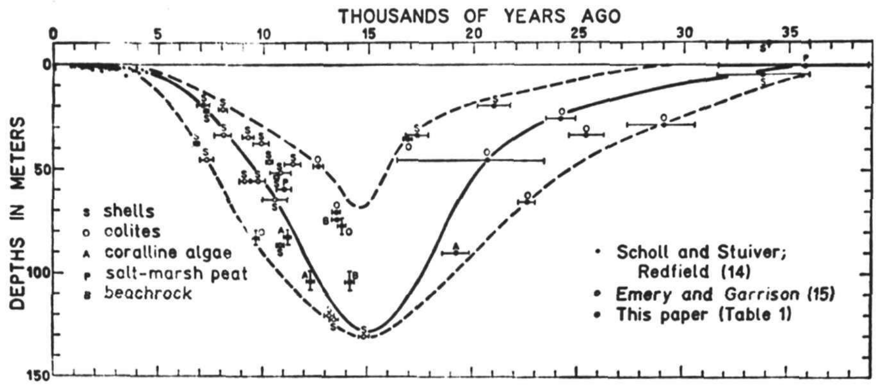


Fig. 3. Sea level curve for the past 35,000 years, showing a low stand about 15,000 years B.P., with a rapid rise until about 5000 years B.P. and a more gradual rise since then. (*From* Milliman and Emery 1968)

2
Origins and Maintenance of Barrier Islands and Capes

Most of the National Seashores have been established on barrier islands and outer capes, except for Cape Cod, which is mostly an eroding headland with barrier spits attached. Barrier islands are low strips of sand parallel to the shore, usually with broad salt marshes and estuaries behind them. Some distance back from the beach are lines of dunes, which may form irregularly or in specific patterns. Shrublands and grassland are the typical vegetation, although woodlands may grow up where the land is high enough or back far enough from the beach. It is natural for high storm waves to break across certain islands, sometimes flooding most of their area.

ORIGINS

Geologists have argued heatedly about the origin of the barrier beaches. Modern stratigraphic evidence has recently repudiated the theories of Johnson (1919), which held that the islands were formed as the ocean pushed up ridges of sand off the sea bottom, with new islands continually forming offshore. Two other basic theories are presently being debated. Fisher (1962), and others, proposed that the barrier islands began as spits downdrift from eroding headlands. As the rising sea battered glacial deposits and sedimentary headlands, the littoral currents laid out the eroded sand in ever-lengthening spits. Then storms drove inlets through the spits at narrow places and cut them up into barrier islands (Fig. 4). The best evidence for this theory is that one can see all these processes going on today. Chapman (1960) and Redfield (1965) showed that marsh deposits progress in age from one end of a barrier spit to the other, with the youngest material behind the downdrift end. Flying over barrier islands, one often sees old dune lines, standing out because of their dark cover of trees, in parallel curves that follow spit growth (Fig. 77).

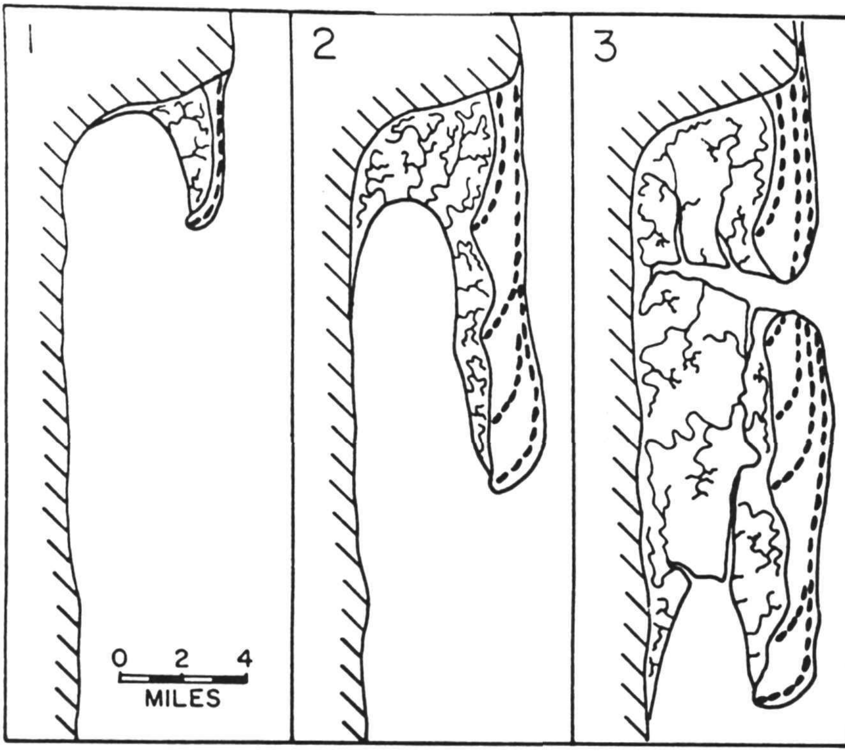


Fig. 4. Spit theory of barrier island formation. Erosion of headland creates elongating spit down current, which is followed by marsh development. Spit breaks and forms an island. (*From* Hoyt 1967)

A second theory, proposed by Hoyt (1967) and others, maintains that the present barrier system formed during approximately the last 5000 years when Holocene sea-level rise slowed down somewhat. During this period, dune ridges had a chance to build up along a shoreline that was some distance seaward of the present coast, depending on the slope of the coastal plain. The rising sea then isolated the dune ridges from the mainland and lagoons formed behind them (Figs. 5 and 6). Continuing sea-level rise resulted in a general retreat of these islands and their associated marshes. During periods of no change or drop in sea-level, the beaches would build seaward and dune lines would form behind the beaches as they prograded. Another rise of sea level would result in retreat. There is ample evidence to support this theory. Mainland sediments deposited before the last glaciation extend under the lagoons to the barrier beach; stumps of trees have been found in the lagoons as well. On the seaward side, salt-marsh peat and the stumps of old forests

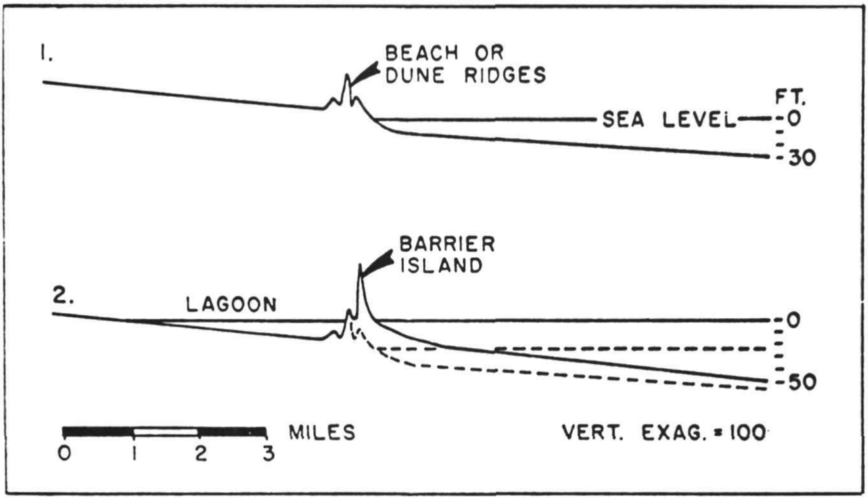


Fig. 5. Drowned beach ridge theory of barrier island formation. Rising sea level isolates a dune ridge and floods mainland behind, creating a lagoon. (*From* Hoyt 1967)

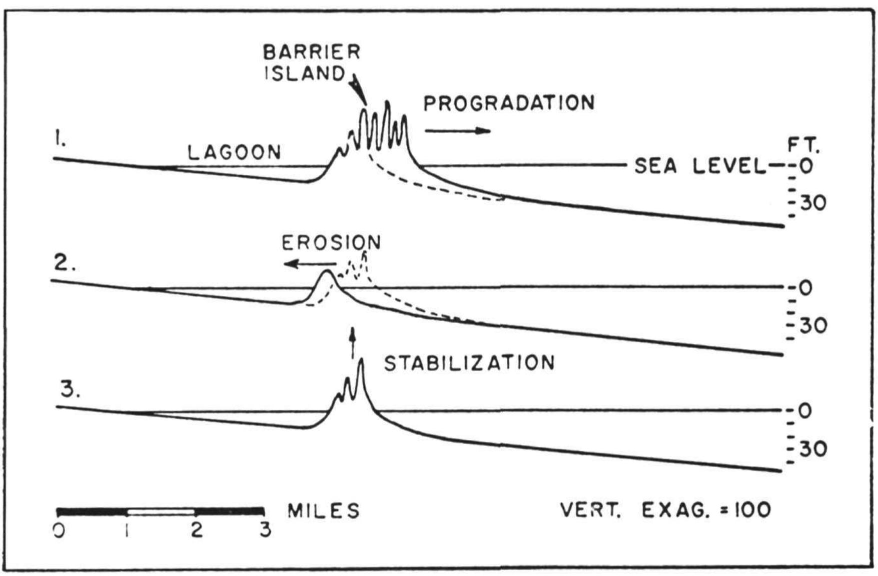


Fig. 6. Response of barrier islands under various conditions: progradation where supply of sediments is in excess; erosion where sediment supply is low; stabilization where supply and erosion are balanced. (*From* Hoyt 1967)

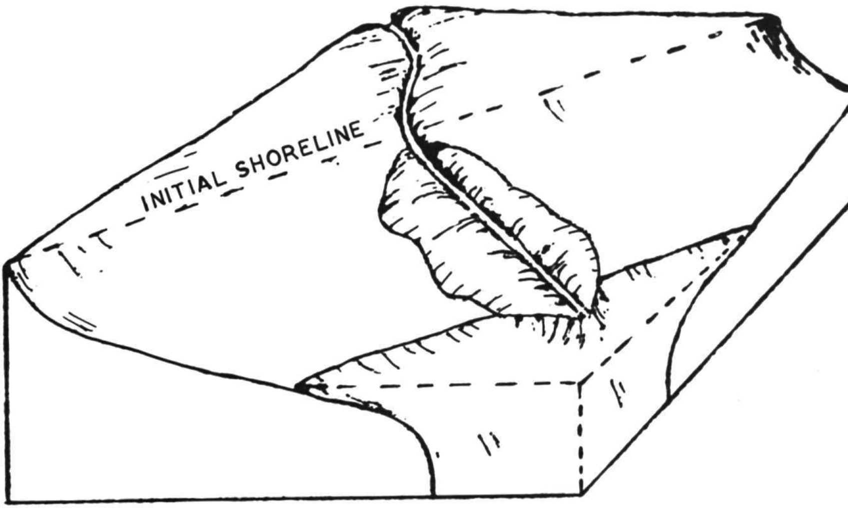


Fig. 7. Idealized diagram showing deltaic ridge on continental shelf formed from abundant river sediments supplied as a result of an increase in the river gradient. (*From* Hoyt and Henry 1971)

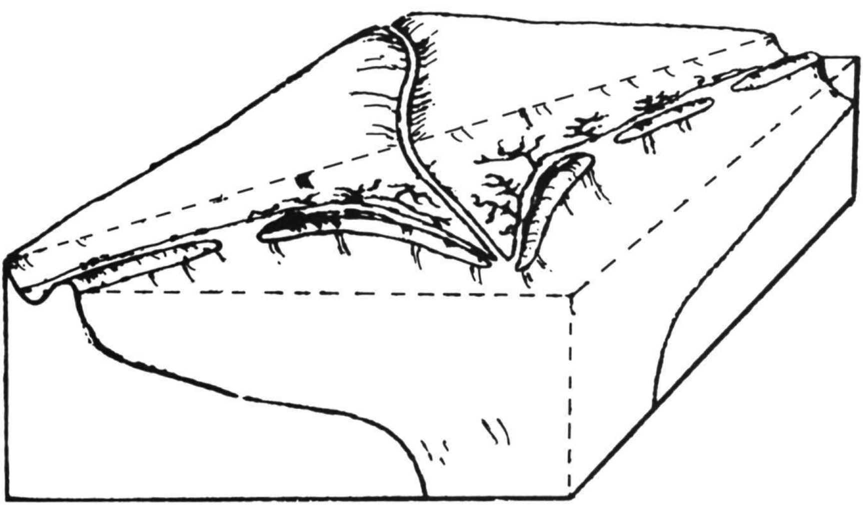


Fig. 8. Idealized diagram showing results of continuing slow submergence and barrier island retreat, which resulted in present cape morphology. (*From* Hoyt and Henry 1971)

may occasionally be seen on the beach at low tide. The shells of typically estuarine mollusks are buried deep in the sediments behind the barrier system; one would expect to find such shells only near the surface if the lagoons had been sea bottom as proposed by Johnson (1919).

It appears that the spit theory is probably the major means by which barrier islands formed north of the glacial boundary, where plenty of easily eroded gravel and sand must have been left in the glacial moraines and headlands. The submergence of dune ridges probably was the major way in which the southern coastal islands, most notably the Sea Islands, were formed. The Outer Banks probably represent a combination of the two, with submergence being the primary process. The formation of spits is also readily seen on the Outer Banks, and one whole island, Shackleford Banks, seems to have been built mainly by spit growth.

The origins of major capes are tied to barrier-island formation. Dolan and Ferm (1968) observed that the capes along the East Coast fit nicely into the eddy patterns of ocean currents; sand carried by littoral drift is dropped wherever the eddies border one another. Hoyt and Henry (1971), however, believed that the capes represent eroded fluvial deposits and that their locations correspond to the mouths of major river systems that flowed across the Pleistocene coastal plain. These deposits were then pushed back by the rising sea, and joined dune ridges which formed along the shoreline (Figs. 7 and 8). Pierce and Colquhoun (1970) proposed that the Outer Banks have changed position since their original formation, with certain portions once further seaward and others behind the present islands. They hypothesize that Cape Hatteras and Cape Lookout were originally both further north of their present positions and migrated south. Schwartz (1971) took the middle ground and proposed that the differing hypotheses reflect a "multiple causality" of barrier-island formation; he presents a classification scheme that incorporates these various ideas: I. Primary 1. Engulfed beach ridges; II. Secondary 1. Breached spits, 2. Emergent offshore bars—a. sea-level rise, b. sea-level fall; III. Composite.

SHORELINE CHANGE

Discussion of these formation patterns will no doubt go on for some time. Of primary importance to coastal management, however, is the fact that the shorelines have changed dramatically during the last several thousand years, that they are changing today, and that they will continue to do so. Sea-level rise has resulted in a worldwide pattern of shoreline recession, or erosion. Such a general recession is likely to continue as long as the sea continues to rise. Indeed, it is absurd to expect

the "natural ecology" of these islands to be the same today as it was sometime in the past. Barrier islands are not like the much more stable lands of the interior, such as the Appalachian highlands or Piedmont, where ecosystems have changed little for thousands, even millions, of years. The whole barrier-island system is less than 5000 years old, and any particular surface may be only a few hundred years old. Indeed, some alterations can be measured in decades. This frequent rearrangement itself is a major part of the "natural ecology." Even so, there have been some sort of coastal ecosystems in one place or another for countless eons throughout the rise of higher plants; otherwise, the vegetation could not have adapted to this difficult environment. The ability of these ecosystems to survive the constant physical alterations of their environment is testimony to the long-term, dynamic stability of barrier islands.

BEACH CYCLES

Short-term changes in beach widths and profiles have been clearly demonstrated. The fact that beaches grow seaward during the low wave energy regime of the summer and retreat when the waves strengthen in winter and during storms is well known. Dolan (in press) has also shown dramatic short-term alterations in beach widths superimposed upon the major cycles. He describes the movement of "sand waves" along the beach, noting how the beach will build seaward as the crest of a wave goes by, and retreat at that same point when the trough of the wave passes. The beach is thus not a simple straight-line system, but a complex series of undulations.

SHORELINE RETREAT—EROSION

Shorelines retreat by two basic methods. Where the beach rises to an erodable cliff or very high dunes, the sea will cut an erosion scarp and the land will retreat, with sand being carried away by littoral currents. In these cases where there is a barrier to the movement of high water, there will be a very narrow berm and the high water will often reach the foot of the scarp (Dolan in press). This is the typical pattern of erosion on many shorelines that have been "stabilized" by engineering structures that are now too close to the sea, or those that are geologically high, such as the sea cliffs on Cape Cod and certain natural, retreating dune areas.

SHORELINE RETREAT—OVERWASH

Along most of the low barrier islands of the eastern shoreline, and particularly the Outer Banks, there is a second method of retreat where it is not blocked by man-made dikes. In this system, storm winds and high water move sand (overwash) back across the berm, through dune lines, and toward the rear of the barrier island, and often into the lagoon behind. On some low islands this is a yearly event. When the high water retreats, the wind blows more sand back from the beach, if the island lies more or less at right angles to the prevailing winds. When islands lie parallel to the winds, as do Core Banks, sand is moved up and down, or off, the beach. Sand pushed into the interior of the island by overwash supplies material for later dune growth (Fig. 6). In most cases, overwash has been considered destructive because sand is removed from the beach and often appears to damage the surface over which it flows. In actuality, however, overwash is a constructive process which permits the low barrier islands to retreat as a complete system, as long as grassland vegetation is present to interact with the overwash.

3
Overwash Studies at Cape Lookout National Seashore

To our knowledge, no studies had been done on the short-term ecological effects of overwash as they relate to the whole barrier-island system before our work, which was first described in the 1970 Annual Report of the Office of Natural Science (Godfrey 1970). Yet the overwash process is the key to understanding how low barrier islands can survive a slowly rising sea level (Shepard 1963).

The boundaries of Cape Lookout National Seashore, where we began our studies as part of a program initiated by its first Superintendent, Mr. Thomas Morse, encompass the southern half of the Outer Banks from Ocracoke Inlet to Beaufort Inlet (Fig. 9). Shackleford Banks (Fig. 10A) is separated from Cape Lookout by Barden Inlet, from which it extends west to Beaufort Inlet. The island can be divided into a western half, with large dunes and a typical maritime forest, and an eastern half which is low, flat, and covered with grass and shrubs, although it was wooded in the last century. North of Shackleford, across Back Sound, are the towns of Beaufort and Harkers Island.

The focal point of this seashore is the triangular Cape Lookout (Fig. 10B) which has had a history of dramatic reorientations to be discussed later. Development of the cape consists of scattered houses, a Coast Guard station, a marina, and the Cape Lookout Lighthouse, dating from 1859.

Core Banks, the major portion of Cape Lookout National Seashore, arcs northeastward from Cape Lookout toward Cape Hatteras. Its characteristic features are a wide berm, low dune lines, strips of grassland behind the dunes, with shrub thickets and a few hammocks scattered along its length, and extensive salt marshes behind the barrier (Fig. 10C). Core Banks is broken today by "new" Drum Inlet, created by the U.S. Army Corps of Engineers just south of "old" Drum Inlet, a natural opening which closed in 1971 (Fig. 10D). The island stretches northeastward from the wide shoals behind old Drum Inlet to the site of Swash Inlet, which has opened and closed repeatedly, and separates

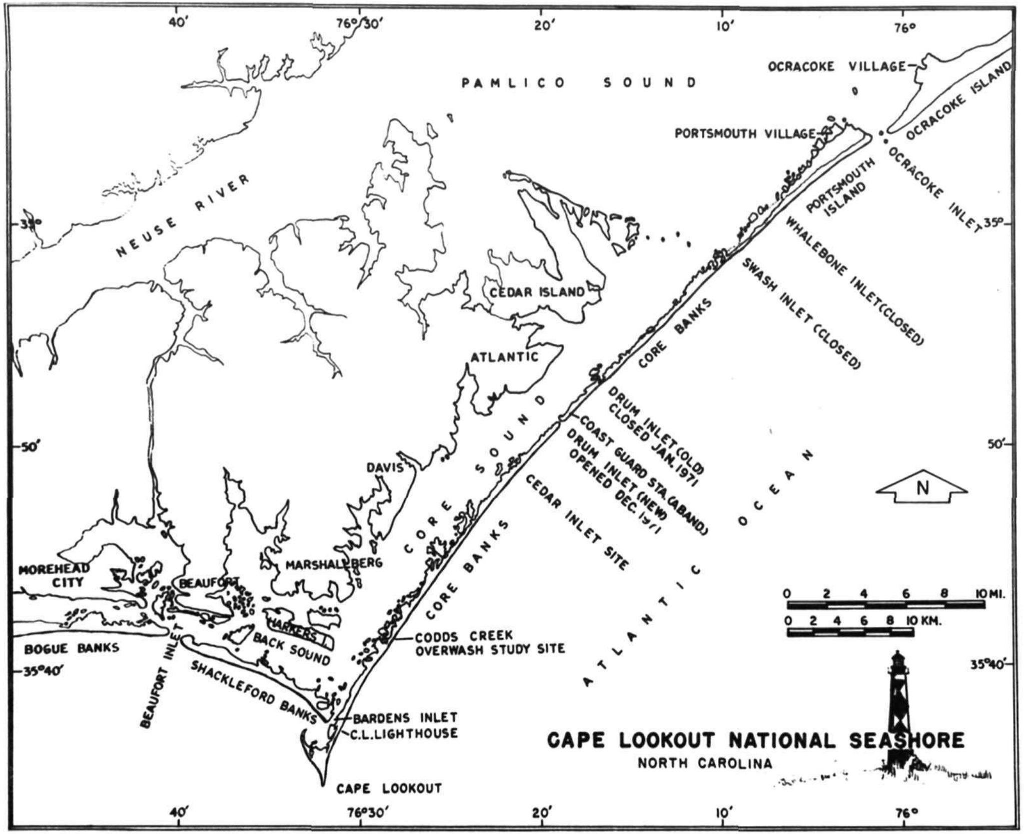


Fig. 9. Map of Cape Lookout National Seashore showing major study areas described in text.

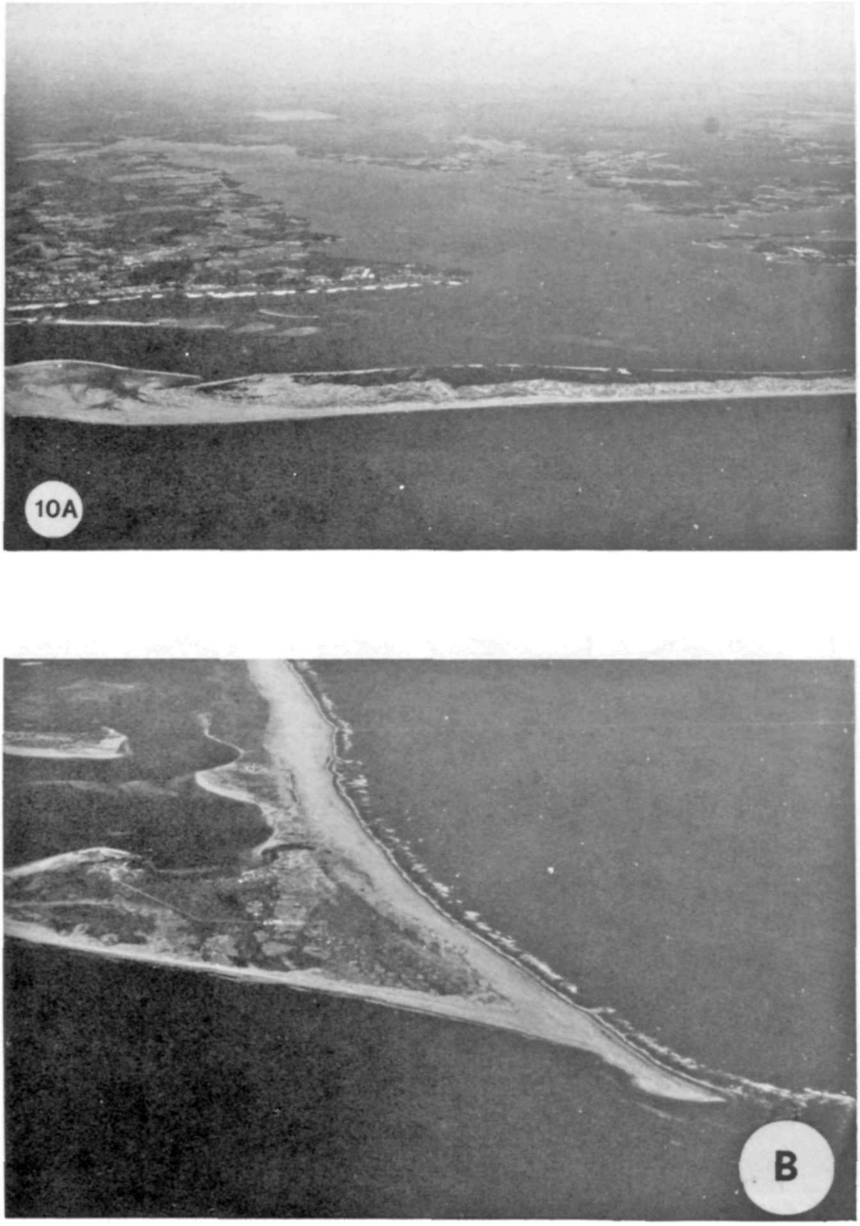
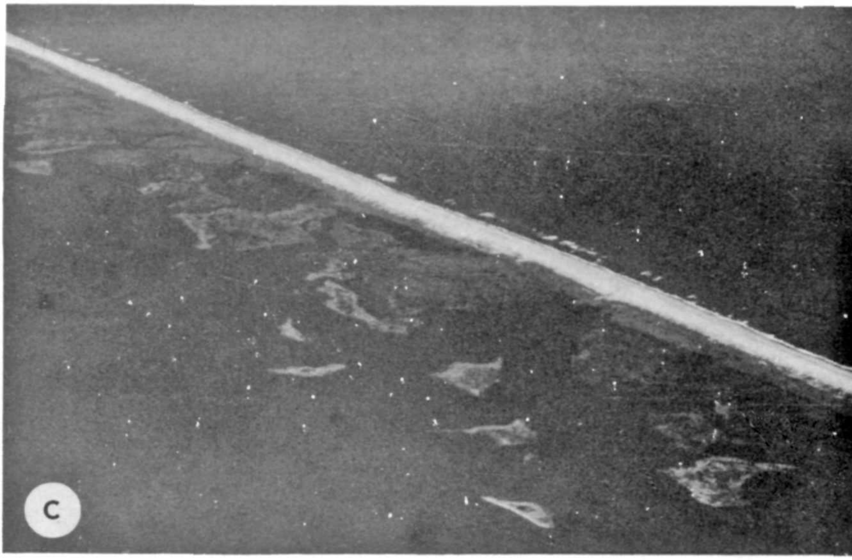


Fig. 10. Aerial views of Cape Lookout National Seashore and its environs: (*A*) Shackleford Banks looking north to Beaufort on the left, North River, Harker's Island on the right, and eastern Carteret County. (*B*) Cape Lookout and view north up Core Banks and Core Sound. The eastern end of Shackleford Banks is on the left, separated from Core Banks by Bârden ➤



Inlet. *(C)* Southern Core Banks in the Codd's Creek area: a typical view of an undeveloped barrier island. Note the extensive salt marsh islands and the remarkably regular beach width all along this shoreline (alt. = 8900 ft). *(D)* Old and new Drum Inlets on Core Banks. The shoals of old Drum Inlet, which closed in January 1971, can be seen on the right, and new Drum Inlet, opened by the Corps of Engineers in December 1971, is on the left. Spoil ➤

from the dredging was spread out behind Core Banks. Between the two sites is the abandoned Atlantic Coast Guard station. *(E)* View north of old Drum Inlet and northern Core Banks. *(F)* Crossing over the southern end of Portsmouth Island, looking south to the sites of Whalebone Inlet and Swash Inlet in the distance. Marsh islands are on the ➤

right and the beach on the left. Note the extensive barren flats that are awash at high tide. *(G)* Portsmouth Village and Ocracoke Inlet. *(H)* Ocracoke Island and the start of Cape Hatteras National Seashore. The straight patches of grass in the foreground are stabilization projects.

Core Banks from Portsmouth Island (Fig. 10E). This latter island (Fig. 10F) differs from Core Banks in that it has an exceptionally low and wide stretch of sand between the berm and the salt-marsh islands behind. These barren, often flooded flats are widest opposite Portsmouth Village, now abandoned except for summer residents, at the northern end of the seashore (Fig. 10G). Portsmouth Village was the largest town on the Outer Banks in the early and mid-1800s; its unique history was recounted by Holland (1968). Beyond Ocracoke Inlet lies Ocracoke Island (Fig. 10H) and Cape Hatteras National Seashore with its roads and man-made dunes.

In contrast to Cape Hatteras National Seashore, the islands of Cape Lookout are largely in their natural state except for a few fishing camps and the tracks of beach vehicles. The only heavily visited area is Cape Lookout, which is served by a passenger ferry. There are no permanent roads on these islands, nor bridges to them, so this seashore has been spared the development and stabilization programs common to other coastal areas. These conditions, then, afforded us the opportunity to study the natural processes of a barrier chain before any drastic alterations began.

The fact that dramatic changes have occurred on these islands over the last century is clearly evident from old maps and records, as well as from present-day field data. Figure 11A shows the appearance of Shackleford Banks and Cape Lookout in the mid-1800s. At that time, Beaufort Inlet was considerably wider than at present, Shackleford was almost completely wooded, and it was connected to Core Banks. Cape Lookout was an elongated point extending southward from the junction of Core Banks and Shackleford. In the late 1800s a series of severe hurricanes started a series of changes that have continued to this day. The storms tore down the protecting seaward dune ridge and permitted sand to start moving across Shackleford. Diamond City was severely damaged and soon abandoned. In the early 1900s the formerly extensive forest was being buried by moving sand dunes, causing great alarm (Lewis 1917). Engels (1952) was one of the first investigators to point out the changes that occurred on Shackleford and to suggest that these were due to natural events rather than to human activities. Nevertheless, Shackleford today shows definite changes from a century ago (Fig. 11B). The end of the island has extended into Beaufort Inlet, following the typical pattern of spit growth. Only a small remnant of the forest remains on the western half, although most of the migrating dunes have since been stabilized by natural means. In 1933, a severe hurricane broke open Barden Inlet, which has since been dredged yearly.

Cape Lookout changed more dramatically than Shackleford, in part due to a jetty built out from its western side in the early 1900s. The Cape changed from a narrowly elongated triangle to a more equilateral

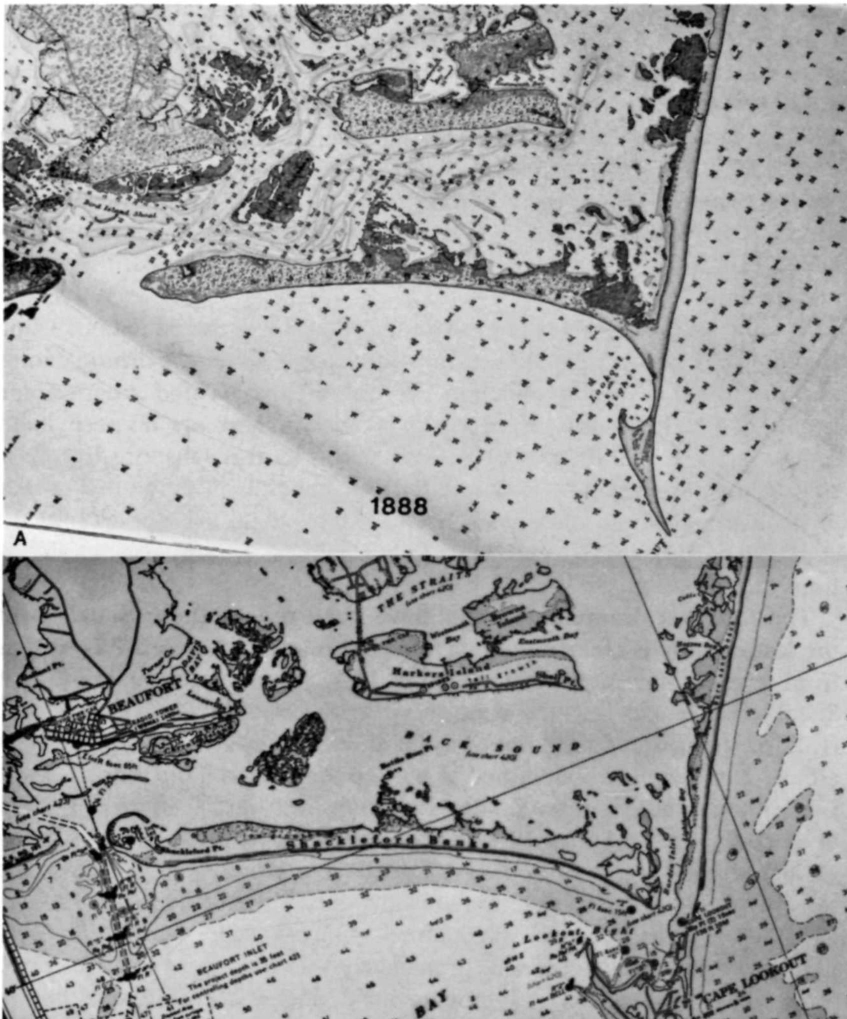


Fig. 11. Physiographic changes of Shackleford Banks and Cape Lookout as seen on Coast and Geodetic Survey coastal charts. (*A*) First issue of 1888, showing Shackleford and Cape Lookout as they appeared between 1850 and 1870. Note extensive forest cover on Shackleford all the way to its eastern end, when still connected to Core Banks. Cape Lookout was long and narrow. Mullet Pond on western end of Shackleford was a salt water bay. (*B*) Issue of 1966. Forest cover on Shackleford greatly reduced and confined to western half. West end grew into Beaufort Inlet. Mullet Pond sealed and now fresh water. Barden Inlet opened in 1933. Cape Lookout shifted position and acquired a more equilaterally triangular shape.

triangle. The western point moved west as a result of the jetty. Cape Point retreated somewhat and also moved eastward. Dune lines which represent the old cape orientation are being truncated where they meet the beach on the southwest side (Fig. 130). These are the highest dunes of the cape and the site of World War II gun mounts, which are now falling into the sea. The cape has not lost total land area through this erosion. Sand has simply shifted from one point to another, in relation to continuing beach processes.

Despite the dramatic changes that occurred on Shackleford and Cape Lookout, many other areas of the seashore have undergone relatively little rearrangement since the first accurate maps were made in the mid-1800s. Topographic maps from that time, made by triangulation, are not exactly the same as modern maps made from aerial photographs, but they show features remarkably similar to those seen today (Fig. 12). The marshes and creeks are almost the same, as are the wide beaches with scattered woodlands. Considering the position of the beach, however, and taking into account the inherent errors in comparing old and new maps, it is clear that the barrier chain has retreated from its position in 1850. Yet, the physiography of the islands has remained the same, and it is this sameness over time in an environment of constant change that leads one to suspect that stabilizing forces are at work on the islands.

Direct evidence of geomorphic and ecological changes can be found in many places on the Outer Banks. The "ghost forest" of Shackleford Banks is populated by picturesquely shaped remnants of cedar trees, in many places still standing on the old forest floor, and exposed as the dunes migrated away from these woodlands which they buried earlier in this century (Fig. 13). Such dead remnants are common on the seaward side of the existing woodlands along the western half of the island. More direct evidence of dramatic change is the layers of peat and stumps that frequently are found along the ocean beaches of the Outer Banks at low tide. Such an outcrop found on Shackleford (Fig. 14) indicated that a swamp forest of some type existed there around 200 years ago when sea level was lower and the beach much farther to the south. Likewise, stumps commonly found in what are now salt marshes along the back side of Shackleford, where old maps of the last century indicated living forests, are clear evidence of recent sea-level rise (Fig. 15). Such stumps are anchored in the sand, and tidal marsh vegetation has migrated onto what were once uplands.

The eastern end of Shackleford once supported the "town" of Diamond City, abandoned in the later 1800s, and today, where the land was once wooded, there are grasslands and marshes. From the air, distinctive strips of open sand, back from the beach, can be seen along the eastern end of the seashore (Fig. 16). Such open strips are overwash

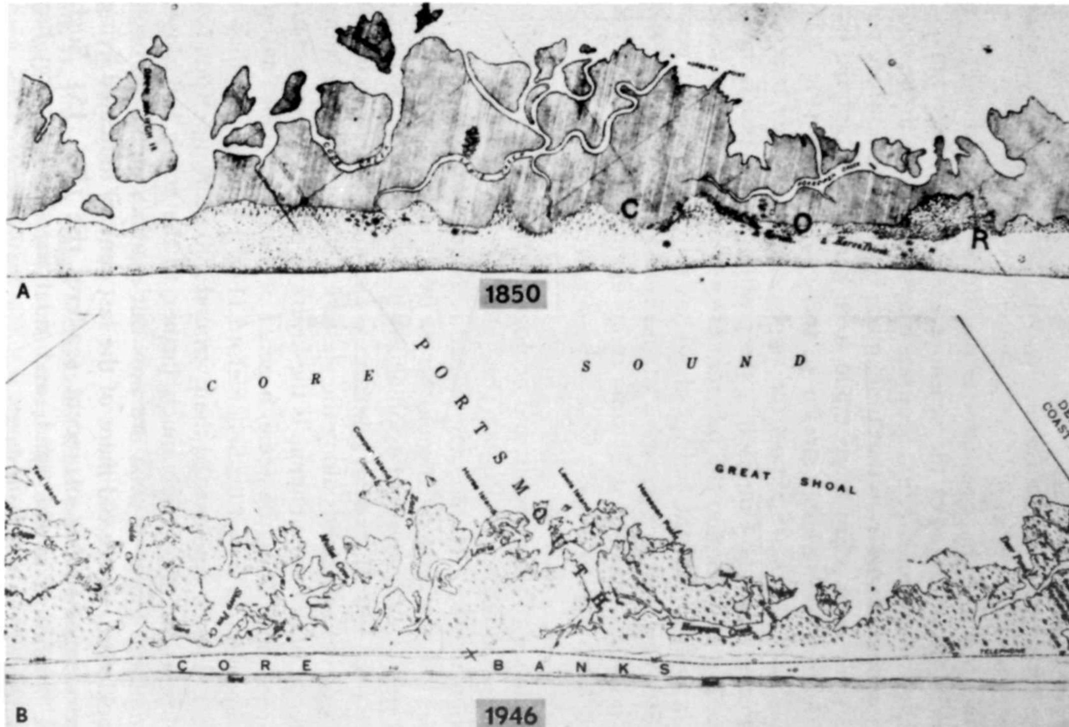


Fig. 12. Maps nearly a century apart of Core Banks. (*A*) Core Banks between 1850–70 (*from* U.S. Coast and Geodetic Survey map 1888). Note extensive marshes and wide, uniform beach. Near Horsepen Creek on right side was a small woodland. (*B*) Latest topographic map (U.S. Geological Survey 1946) of the same area in (*A*). Aerial photographs result in a more accurate map than triangulation, hence the two are not strictly comparable. Note, however, the great similarity between the two: extensive marshes and wide uniform beach berm. Woodland shown in 1850 has a counterpart in the same area today.

Fig. 13. Former forest on the west end of Shackleford. In early 1900, the forest was buried by dunes which have since migrated away, exposing remains of cedar trees and the forest floor. Such views are common on the southern half of the island facing the sea, and are direct evidence of once more extensive forest.

Fig. 14. Stumps and peat exposed at low tide on the ocean beach near the middle of Shackleford. The peat strata suggest formation under a wooded fresh water swamp; samples dated by Carbon-14 were less than 200 years old. Similar "drowned forests" are frequently seen along the beaches of the Outer Banks and other barrier islands. Salt marsh peat strata are likewise commonly found at low tide line on beaches. Peat exposures can be regularly found after severe storms on Core Banks. Such evidence indicates major physiographic changes, with marked retreat of the islands, and a lower sea level when the forests and marshes were alive.

Fig. 15. A salt marsh with tree stumps on the eastern end of Shackleford, where maps of a century ago showed forest. Rising sea level apparently changed a woodland to a marsh in that time.

Fig. 16. Western end of Shackleford showing a characteristic feature of most of the Outer Banks: overwash from high storm tides, the white area in the center of the photograph. This region was forested in the last century and was the site of Diamond City, abandoned in the early 1900s following severe hurricanes in 1899. Fig. 15 was taken in the marshes of this area.

fans consisting of sand pushed into the island from the beach. Old dunes can be seen in the foreground, with overwash passes between them. In areas such as this, and throughout the seashore, soil profiles show layers of organic matter below typical beach sand. In some places, such as the eastern half of Shackleford, the stumps of a destroyed forest stick up through the sand, surrounded by seedlings of the same species, *Juniperus virginianus* (Fig. 17). Diggings around these stumps show that the base of the tree and the old forest floor are indeed covered by sand from the beach, mixed with shells that could only have come from the surf zone. These woodlands were shown on 1850 maps (Fig. 11A), so we know they were alive then. The trees apparently died when sand was pushed in from the beach; the level of the land rose anywhere from 0.25 to 0.5 m, and the water table rose with the new deposits flooding out these mesophytic trees.

The rate of overwash build-up was determined from historical aerial photographs and from surveys of change in elevation relative to permanent bench marks established by the U.S. Army Corps of Engineers in 1960 between Cape Lookout and Ocracoke Inlet. The Corps set out 77 lines of these bench marks perpendicular to the beach and 3000 ft (914.4 m) apart, with three or more markers in each line 100 ft (30.5 m) apart. Each iron pipe marker had a concrete base poured around it at the level of the sand when the pipe was installed, so that changes relative to these concrete bases can be determined (Figs. 18 and 19). All lines still in place were evaluated. Some of the markers had been damaged during severe storms of the early 1960s, but these were evaluated by the U.S. Army Corps of Engineers in their project report (U.S. Army Corps of Engineers 1964). Since that time, no others have been lost to the sea, although beach buggies have knocked down a good many. Of the markers still left, we found that the overwhelming majority located some distance from the beach was buried by overwash deposits alone or overwash combined with dune build-up (Fig. 20). Of the markers nearest the beach approximately one-third were eroded, one-third showed no change, and one-third were buried. On the average, the markers from Swash Inlet (south of Portsmouth Island) to Cape Lookout had definite sand build-up around them, but those on Portsmouth Island showed erosion. The southern region has thick grasslands and a low, irregular dune line, while the Portsmouth region is barren and mostly without dunes. Thus, where there is some resistance to water flow, overwash appears to build up the land, yet where there is no resistance, surface erosion can occur.

A series of photographs dating from 1939 shows graphically the pattern of overwash on a section of Core Banks called Codd's Creek (Fig. 21). Before 1968, a large bay reached toward the barrier beach around a triangular marsh peninsula. Following the severe storms of the late

Fig. 17. Many once-wooded areas of western Shackleford still have stumps and snags from the old forest. Soil profiles in these areas invariably show yellow beach sand and shells overlying the old forest floor and tree bases. The old surface in this profile was covered by 40 cm of beach sand. A young red cedar, *Juniperus virginiana*, shows on the left, and in time a new forest may grow up on this elevated surface.

Fig. 18. Profile 14 on Core Banks, showing the bench marks established by the Corps of Engineers in 1960, and elevation changes. When constructed, the concrete base was at the level of the sand. Profile 14.0 in the foreground is now located in an overwash channel and shows some loss of sand from the base; 100 ft back is P 14.1, just visible in the photograph. Sand covers the base of this marker.

Fig. 19. Marker P 14.2, 200 ft from P 14.0, was nearly totally buried by layers of sand washed in from the beach when the photograph was made in 1969. The concrete base is visible at the bottom of the hole. The ruler is 15 cm long. A year later the cap was completely covered.

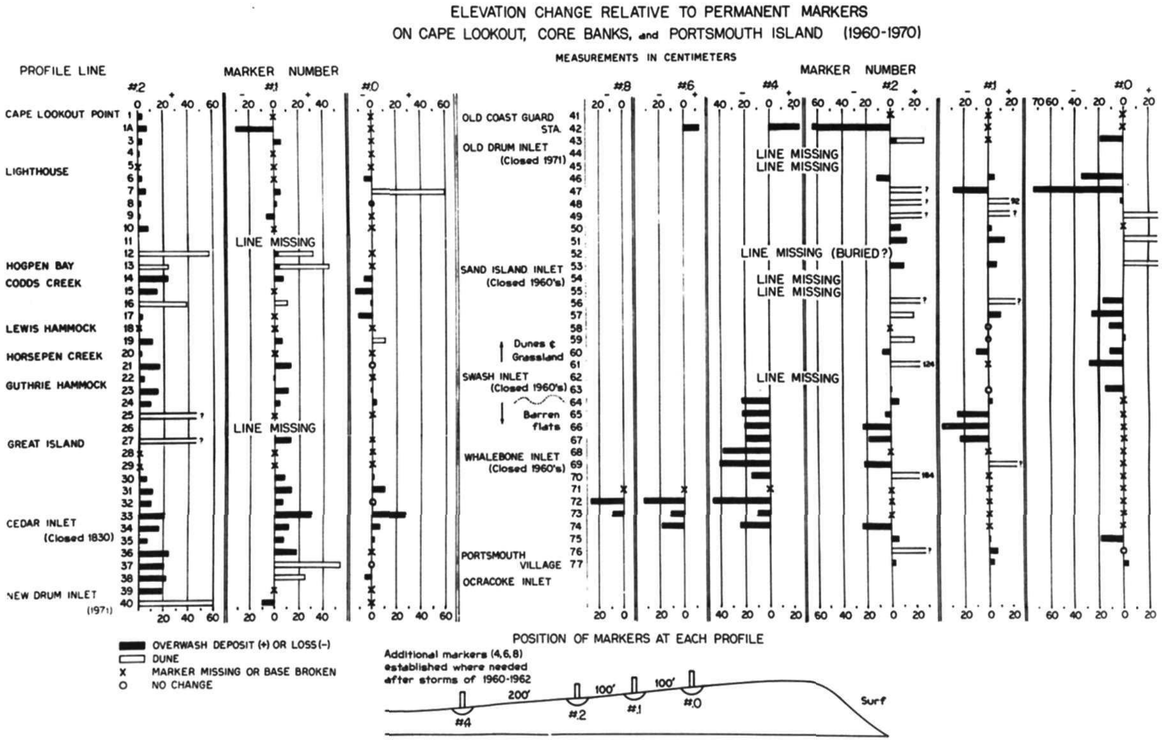


Fig. 20. Elevation changes relative to the permanent markers on as many of the 77 profiles as could be located. Lines were set 3000 ft apart. Nearly all inner markers south of Swash Inlet were buried by overwash deposits, dunes, or both. Only the outermost line showed significant loss on one half of the markers. (Marker 42.2, which shows significant loss, was in a major overwash channel near Drum Inlet.) Such data are direct evidence of overwash build-up on the inner part of Core Banks, where vegetation and low dunes are present. But the barren flats of Portsmouth Island have definitely been lowered by sheet erosion from storm tides and wind.

1950s and early 1960s, a great deal of sand was moved across the island, onto the marsh surface, and into the bay. In the decade since, there has been a continuous build-up of the vegetation on the island; note the enlarging dark patches in the photographs.

Figure 21F summarizes changes during the 28 years since the first pictures were taken. Where there was once open water, there are now salt marshes, grasslands, and dunes. Formerly bare areas have been colonized by grass. As the beach retreated, new land was formed behind the island, with upper parts of the old marsh being covered. There was also an increase in the overall width of the barrier island. With such historic evidence it became clear that overwash was the way the islands retreated. Profiles were made on the island at the sites indicated in Fig. 21E.

Experimental evidence for the response of the typical barrier-island grassland to overwash was obtained from experimental burial boxes. These were set up near Codd's Creek in the flat grasslands behind the dune zone where the vegetation was dominated by *Spartina patens* (salt meadow cordgrass). The boxes were 1 m^2 and filled to depths of 10 and 20 cm with clean, root-free sand. In the case shown in Fig. 22, the grassland was first clipped. Within one growing season (Fig. 22B), *Spartina patens* and *Hydrocotyle bonariensis* (pennywort) began invading the sand. After two growing seasons, the boxes were nearly invisible, so densely did the vegetation colonize the boxes (Fig. 22C). Excavating the sand within the burial boxes showed that the main method of recolonization was the upward growth of rhizomes, primarily of *Spartina patens*, and rerooting near the surface. Figure 22D shows an excavated section with the original surface indicated. Such response by these plants, particularly *Spartina*, verified that this grassland could quickly recover from overwash as suggested by the aerial photographs.

In some cases, as at Codd's Creek, the overwash carried sand completely across the island and into the lagoon behind. A dramatic example of this process and the ecological response were seen at the site of the old Atlantic Coast Guard Station on Core Banks opposite Atlantic, N.C. Figure 23A shows the station in 1962 just after it was abandoned. Up to that time, the sound behind the station was dredged for boat access; the small arrow indicates a mooring post. The station site in 1971 is shown in Fig. 23B. In the few years since maintenance ceased, overwash sand has filled the lagoon so that new marshes are developing. Note the same mooring post indicated by the arrow. Figure 23C shows the old sea wall in the foreground, the dock, and the new salt marsh that formed where once boats were moored. The post in the left background is the one marked by an arrow in the aerial photographs. Figure 23D is a view along the back side of the island, showing the extent of the new salt marsh with the sea wall on the left. Such evidence clearly illustrates

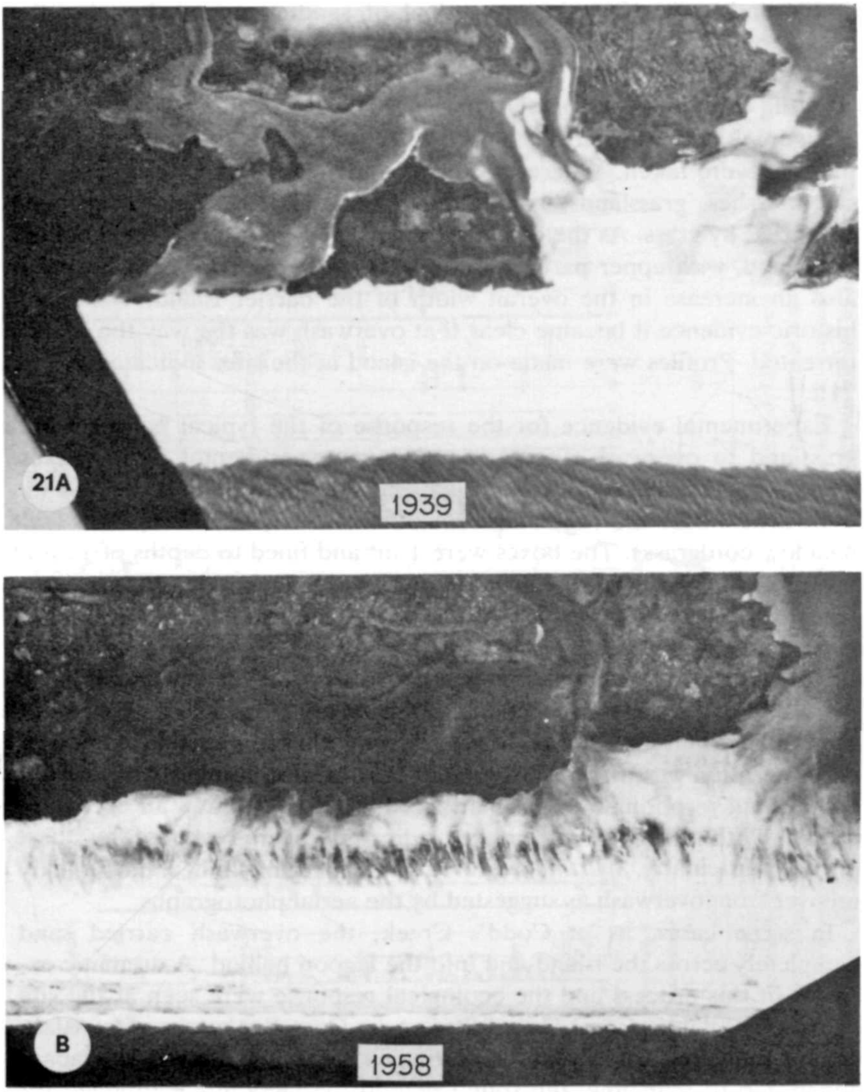
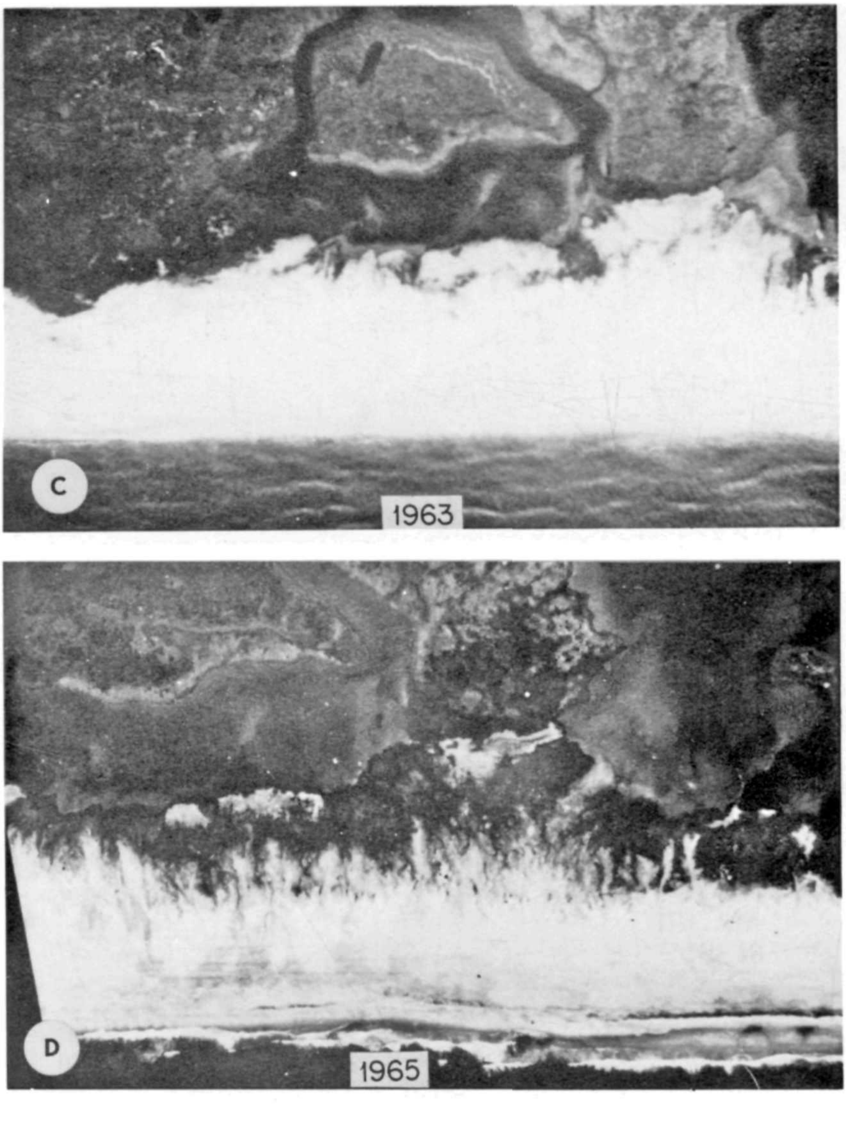
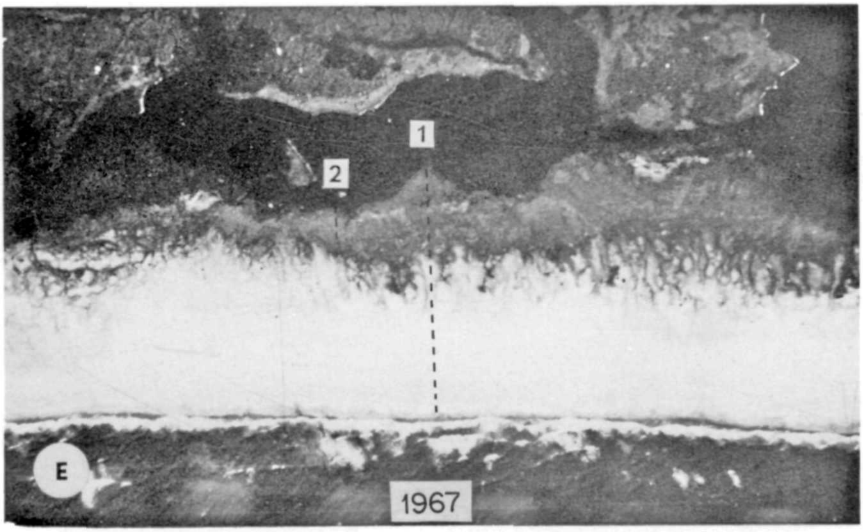
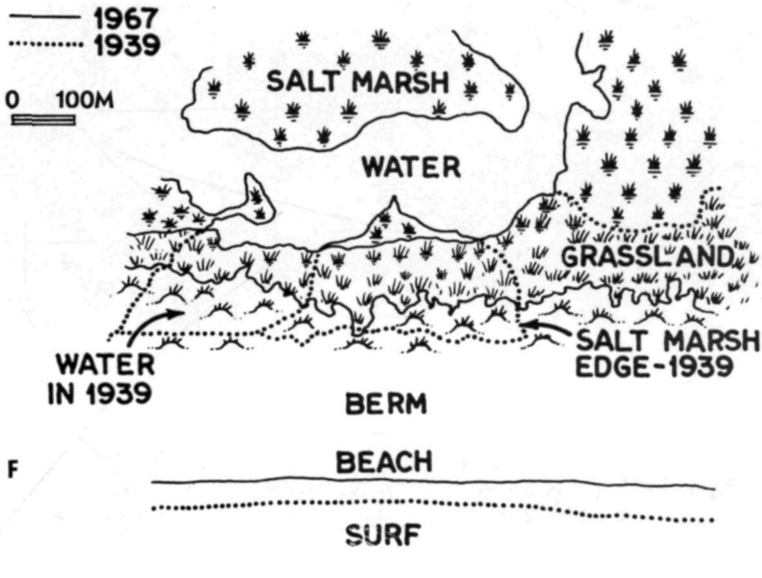


Fig. 21. Changes caused by overwash on Core Banks at Codds Creek. (*A*) The first photograph, taken in 1939, shows an arm of Codds Creek extending well into Core Banks. The large black triangle in the center is salt marsh. Earlier overwash, seen on right, filled in the creek between Core Banks and a marsh island. (*B*) Storms in the 1950s pushed sand across Core Banks, filled in the creek on the left, and covered part of the marsh, leaving a small triangle at the edge of the new deposit. It was during this time that livestock were removed from the islands. (*C*) By 1963, vegetation, probably marsh, began invading the new surfaces, as seen by the darkening in the photograph. (*D*) Recovery was well advanced in 1965, ►



with grasslands, new dunes, and marshes reestablished. White areas at the edges of the overwash were probably salt pannes. (*E*) A whole new sequence of vegetation zones had completely covered the island up to the new dune line by 1967, and this is how the island appeared in 1972. All signs of earlier overwash have been erased; the banks are widened and in part connected to former salt marsh islands. Dotted lines in the photograph indicate transects discussed in the text and shown in further illustrations. (*F*) Overlay of outlines from 1939 and 1967 showing changes in Core Banks in that time interval. The beach retreated somewhat, while sand pushed back into former water areas is now vegetated. ➤


1
2
E
1967


1967
1939
0 100M
SALT MARSH
WATER
GRASSLAND
WATER
IN 1939
SALT MARSH
EDGE-1939
BERM
F
BEACH
SURF

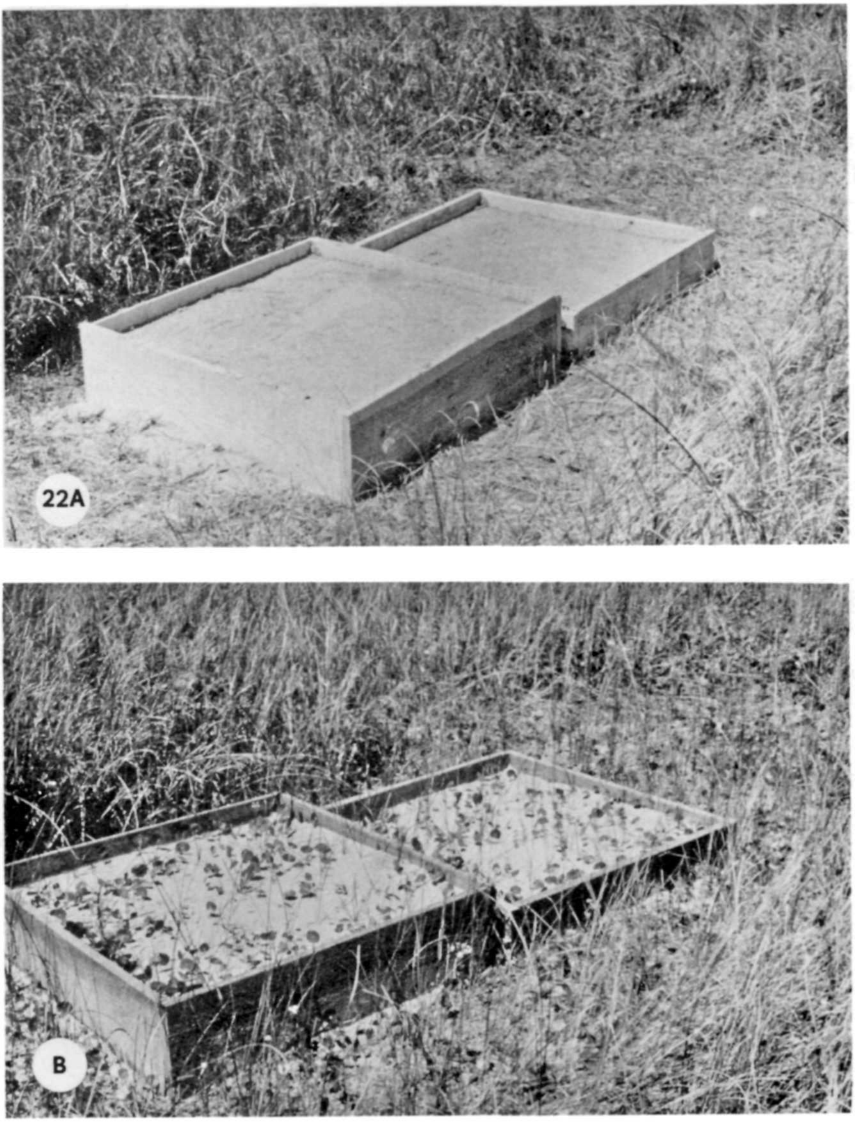
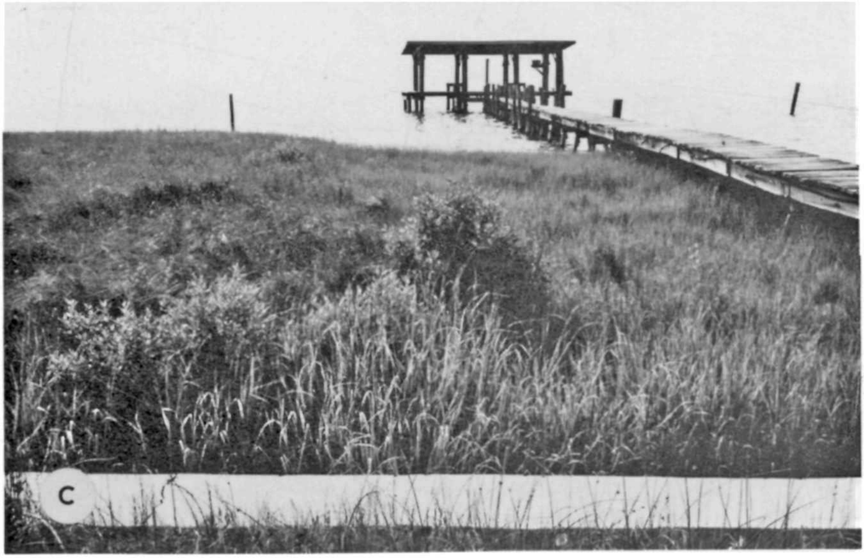


Fig. 22. Response of grassland vegetation to a simulated overwash. (*A*) Meter-square boxes placed on clipped grassland with a control on the right. The boxes were filled to 20 cm or 10 cm with clean beach sand free of roots and rhizomes, June 1970. (*B*) By the end of the 1970 growing season, *Spartina patens*, *Scirpus*, and *Hydrocotyle* had pushed back up through the overlying sand. (*C*) A year later, August 1971, the boxes were nearly obscured by grass regrowth. The standing crop in the 10 cm burial was close to that in the

control; in the 20 cm box it was somewhat less. (*D*) Excavation of the boxes shows the original level of the grassland (knife) and the response of *Spartina patens*, the most important member of the grassland vegetation, to burial. Rhizomes pushed up through the sand from rootstocks below, sent out new roots near the surface, and revegetated the surface. All culms excavated in the boxes were the result of rhizome growth. Such grasslands appear capable of quick recovery from the deep burial of major overwashes.

Fig. 23. (*A*) The Atlantic Coast Guard Station on Core Banks as it looked in 1963. At this time, several years after abandonment, the sound waters still ran up to the sea wall just behind the station. A mooring post is shown by the arrow. (*B*) The same area in Fig. 23A as it looked on 22 January, 1970. (The station burned in 1968.) The sound behind the sea wall has filled in and salt marsh has developed on the natural fill. The old sea wall is still visible, and the arrow shows the same mooring post in Fig. 23A. The overwash fan shown in the lower right corner of Fig. 23A increased in size, as seen here, and is now becoming salt marsh. Vegetative cover, both marsh grass and higher elevation grasslands, ➤



has increased more dramatically. The base on which the marsh is developing has been derived primarily from overwash deposition, and in this manner salt marsh will expand behind the barrier island. An experimental grass planting was made near the mooring post shown by the arrow. (See Figs. 95, 96, 97 for ground views of this planting.) (*C*) View of the new salt marsh growing up in what was once the harbor shown in Fig. 22A. The sea wall is in the foreground. Mooring posts are those visible in the aerial photographs. (*D*) The extent of the new marsh on what was sand a decade ago can be seen in this view looking south with the sea wall on the left.

the manner in which the back sides of the island grow into the sound, and new salt marshes form, as the ocean side retreats. At this particular site, marshes are growing into the lagoon at about 1 m per year.

Ground surveys at Codd's Creek (Fig. 21) were made by means of vegetation transects, mapping, elevational survey, soil profiles, and geological coring. The ecological data will be discussed in the section dealing with ecosystems. Piston cores were taken 30 m apart across the island, down to 2 m where possible. Each core was diagrammed and photographed, and subsamples from each core were saved for analysis. Mollusk shells were identified from selected sections of certain cores. There is a general thinning of sand strata toward the back of the island, which shows the varying effectiveness of storms in moving sand back, with the most severe storms moving sand the farthest. Invariably, however, an organic layer was found somewhat below the surface in the middle of the island, corresponding to organic strata that now exist at the back of the island (Fig. 24). At one point, indicated on the diagram, the surface of a grassland community, probably a high marsh, was covered by nearly 1 m of sand (Fig. 25). This grassland was shown on topographic maps of the late forties and was part of the marsh shown in Fig. 21A. The presence of oceanic shells in these strata suggests that the sand indeed came from the beach. Five species of oceanic mollusks (*Spisula solidissima*, *Donax variabilis*, *Mactra fragilis*, *Dentalium laqueatum*, *Anatina plicatula*) were found in the strata above and below the organic horizons. This clearly shows that the upper layers of this barrier island have been deposited by overwash; wind alone is ruled out since shells weighing up to 0.5 kg were found at different levels through the interior of the island. An accumulation of 1 m of sand in 25 years is rather rapid land building.

Transects across the Codd's Creek salt marsh that formed where overwash deposits went into the lagoon are shown in Figs. 26 and 27. This new, expanding marsh developed in less than a decade and is much more productive than the older, eroding marshes that adjoin it. Tidal water moves freely into the new *Spartina alterniflora* (salt marsh cordgrass) marsh that is growing here at a lower elevation than the older, and hence higher, marsh nearby. The presence of beach shells under this luxuriant marsh grass is clear evidence that the substrate originated from overwash.

The photographs (Fig. 21) also demonstrate that the island retreats as a unit; it apparently maintains the minimum width which will allow storm waves to dissipate the brunt of their energy before getting to the dune line. Waves churn across this berm, demolishing any dunes too close to the beach, and then flow more quietly between the dunes into the grasslands behind them. Energy is further dissipated in the grasslands, where the flow slows down quickly. Thus, most of the sand load

Fig. 24. Two profiles on Codds Creek Transect#1, illustrating the overwash strata which overlie organic layers. (*A*) Profile at position CC 7, showing an overall view of an overwash pass with dunes in the background. This area was a marsh in the 1940s. (*B*) Close-up of ➤

60 cm of strata overlying an organic layer, probably from an old grassland. The alternation of concentrated shells with sand represents successive overwashes. Layers of concentrated shells were probably surfaces from which fine sands were blown away. Water in the pit is ►

fresh. At a depth of about 1 m salt marsh peat was found. The large whelk was found at the bottom of the pit. (*C*) Close-up of strata at position CC 9 in the high marsh vegetation zone. Yellow beach sand layers overlie dark gray sand (a reducing environment with black stains caused by iron sulfides). Ground water is nearly fresh. Dark bands at 13 cm are ilmenite.

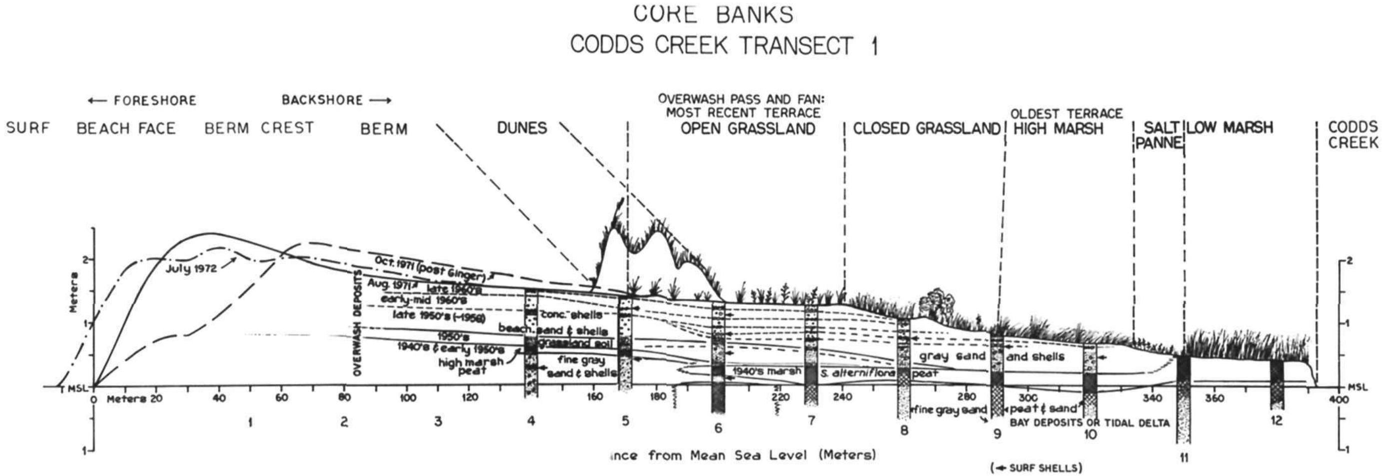


Fig. 25. Diagrammatic cross-section of Core Banks (Transect 1), showing location of cores and general strata through the island surface. Reconstruction of surfaces in hypothetical, based on interpretation of aerial photographs and gross differences between strata. A high proportion of shells was taken to indicate a former surface. Since there are so many such horizontal strata, the island mass plainly consists entirely of overwash deposits. Earlier marsh layers are below these recent strata. In core 8, two marsh surfaces were located, one above another and separated by overwash sediments. The overwash killed part of the marsh, while the uncovered portion continued to grow vertically. This probably caused the difference in elevation of the two surfaces. Also the weight of the overlying sand probably caused some compression of the marsh peat. Arrows indicate selected samples from which surf shells such as *Donax variabilis, Anatina plicatula,* and *Spisula solidissima* were identified. The diagram also shows the effect of Hurricane Ginger in changing the August 1971 berm profile. (*See* Fig. 29). The July 1972 profile clearly shows the recovery of the normal berm shape 10 months after a major storm; the sea level even moved 10 m seaward of its position in 1971.

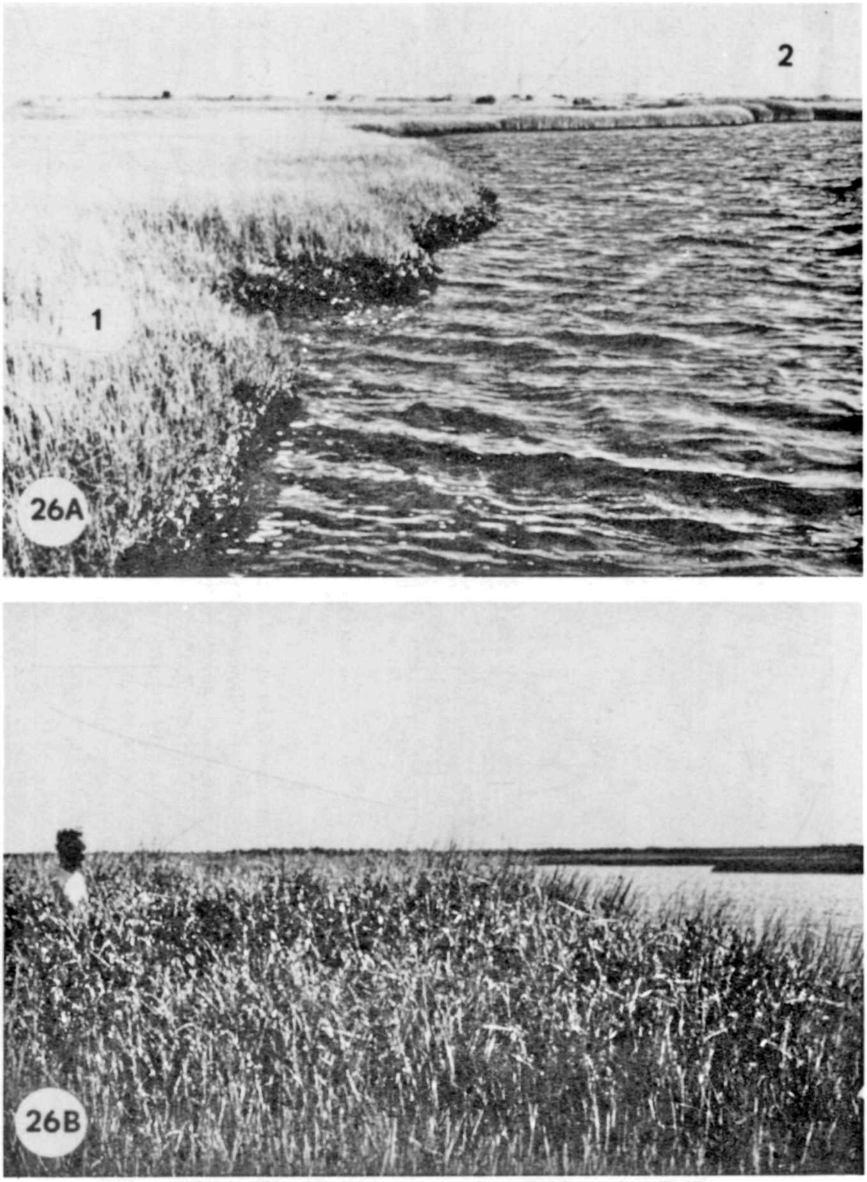


Fig. 26. Differences between old salt marsh surfaces and recent overwash deposit. (*A*) View from the end of Codds Creek Transect 1, showing eroded peat around the marsh and short *Spartina alterniflora*. The tall grass at location 2 on the right is *Spartina* growing in what was part of the creek before overwash filled it during the late 1950s. (*B*) Transect 2 was made through this remarkably tall and productive stand of *Spartina alterniflora*. Here the grass is nearly 2 m tall and is typical of new marsh growth on recent overwash deposits.

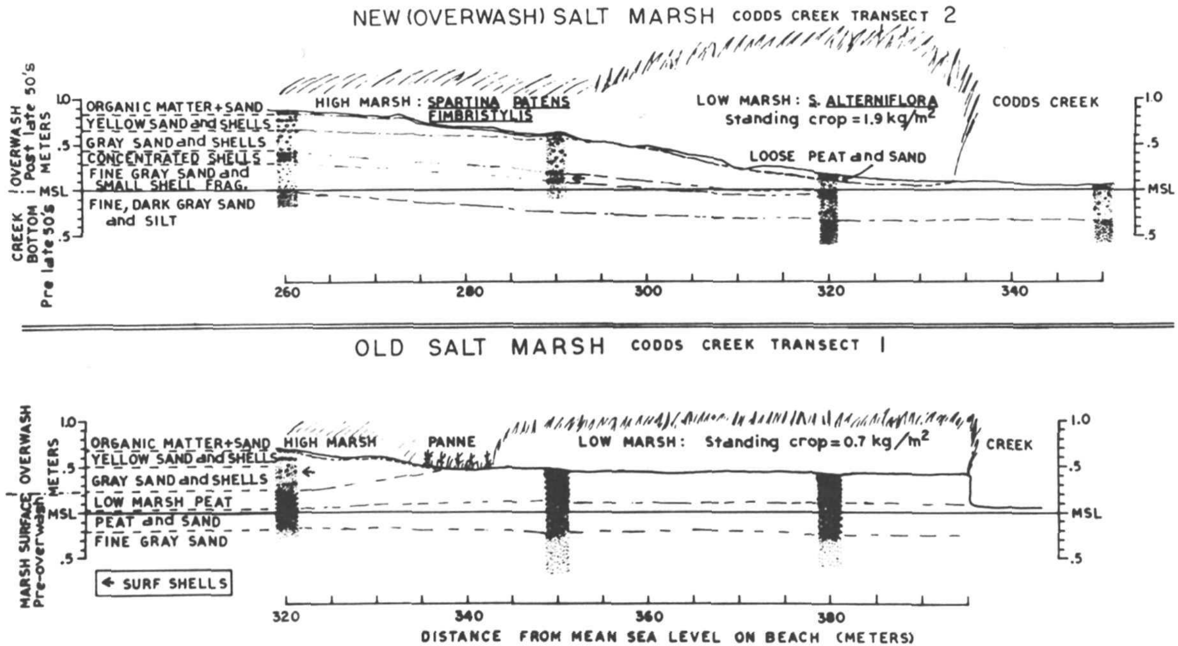


Fig. 27. Diagrammatic cross-section which contrasts the new salt marsh on Transect 2 with the older one on Transect 1. In Transect 2, the overwash created a gradually sloping surface into the creek, which was ideal for colonization by *S. alterniflora*. The marsh is readily flooded by the tides and is of great value to the estuary. Waves are easily dissipated in the grass and no erosion occurs. The marsh can also advance further into the creek on the sediments. It is tall, thick, and highly productive, with nearly three times the standing crop of the nearby old marsh. In Transect 1, the marsh substrate is peat and the plants are of the short form. Waves erode the edge of the marsh peat and the grass cannot invade the creek bottom. Several overwashes may have been involved in creating the substrate for the new marsh. The original creek bottom was very fine sand mixed with silt, and is distinct from the overlying oceanic sediments. The fine gray sand and shells may have come from an earlier, less severe overwash that preceded the major deposition on which the marsh now grows. Gray sand indicated reducing conditions and iron sulfides. Refer to Fig. 21*E* for the location of these transects.

settles out in the dunes and grassland.

Since we began our observations, several storms have struck the islands, and in each case sand was deposited as expected. Hurricane Ginger, in the fall of 1971, was not a really powerful hurricane, but it did considerable damage to some developed beaches and put the Cape Lookout islands under water (Dolan and Godfrey in press). On these islands, instead of damage, there was a definite build-up around elevation markers at Codd's Creek (Fig. 28). On a rather narrow section of Core Banks opposite Atlantic, N.C., as much as 50 cm of sand were deposited on grasslands about 150 m back from the beach (Figs. 29 and 35).

When storm waves strike directly against a stabilized dune line, scarping such as that shown in Fig. 30 is the result. Such erosion may occur when a beach retreats up to a natural or artificial continuous dune line, or when dune lines are built too close to the beach. In either case, wave energy is expended directly against the dune base, undermining the dune and causing the front of the structure to slump. No amount of grass on the dune can prevent this.

Occasionally, stabilized dune lines are broken by storm waves and an overwash fan is formed as sand from the dune is carried back. Figure 31 shows a once-continuous man-made dune on Core Banks which has been broken by storm water. Here, however, the damage was only to the artificial dune itself, since the sand was caught and colonized by grasses behind the dune. It is when there are developments behind such a continuous dune that difficulties result. Figure 32 shows the results of overwash in an area where cottages were built right behind the barrier and are now subject to flooding. Such breaching and flooding can be expected; they are part of the natural pattern of retreat.

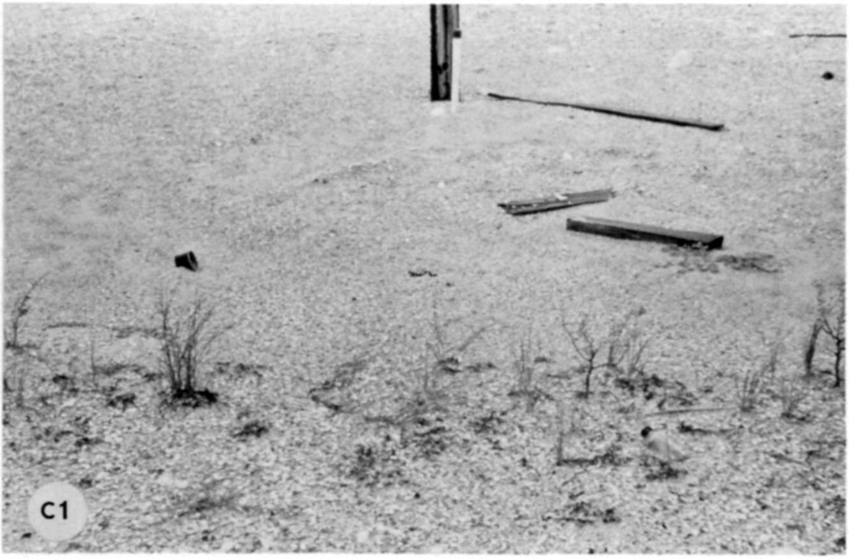
Contrasting with the erosion and breaching of stabilized dunes is the pattern seen on islands with natural, discontinuous dune fields. Here, overwashes carry sand through the dune fields and create fans in low areas behind, as shown in Fig. 33 on Shackleford Banks. This fan is typical of natural beaches; when Hurricane Ginger swept across the Outer Banks, many such fans were produced on Core Banks (Fig. 34). A summary of the overwash process is shown in Fig. 36.

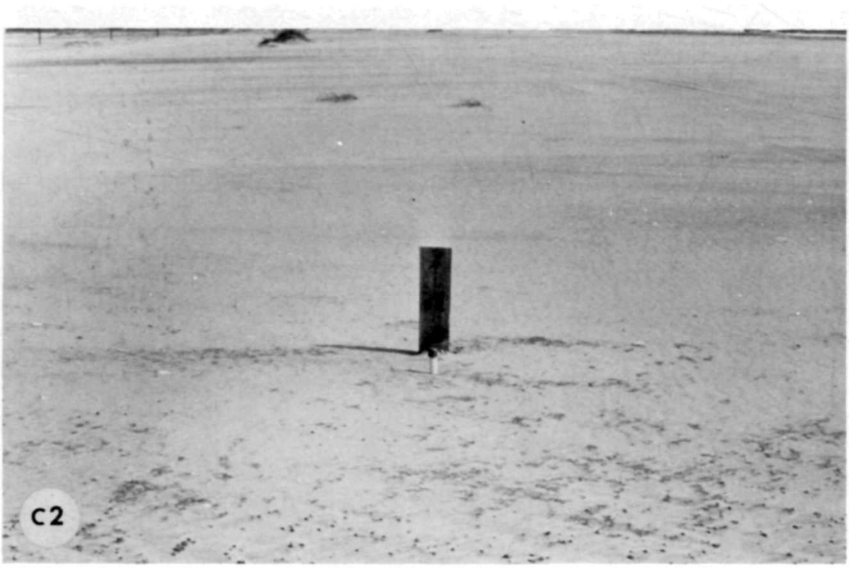
SHORELINE CHANGES

After retreating during storms, the beach will grow seaward. Soon after Ginger, a new berm began building outward with the return of gentler waves. Before that storm, we tried to get some idea of the changes in the beach width since the first survey by the U.S. Army Corps of Engineers in the early 1960s, when the Corps expressed considerable

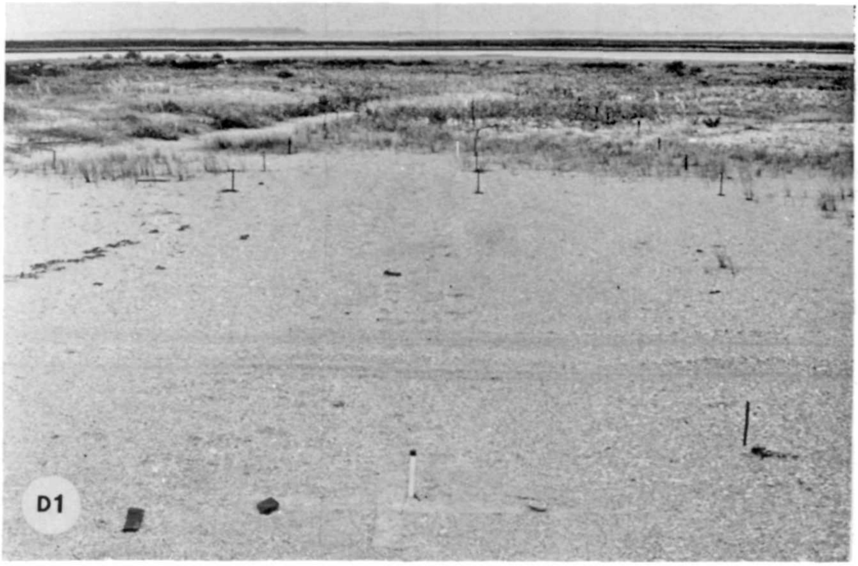
Fig. 28. Effects of Hurricane Ginger, 30 September 1971, on Core Banks at Codds Creek. The hurricane crossed Core Banks between Drum Inlet and Portsmouth Island. Storm surge was 2.5 m above sea level, with winds of 100 kph at Cape Lookout. The banks were completely inundated, with about 0.8 m of water over the backshore at the dune line. (*A1*) Codds Creek transect, shown by dotted line, before Hurricane Ginger. (*A2*) Codds Creek transect after Ginger. (9 October 1971.) Very little evidence of the storm passage ►

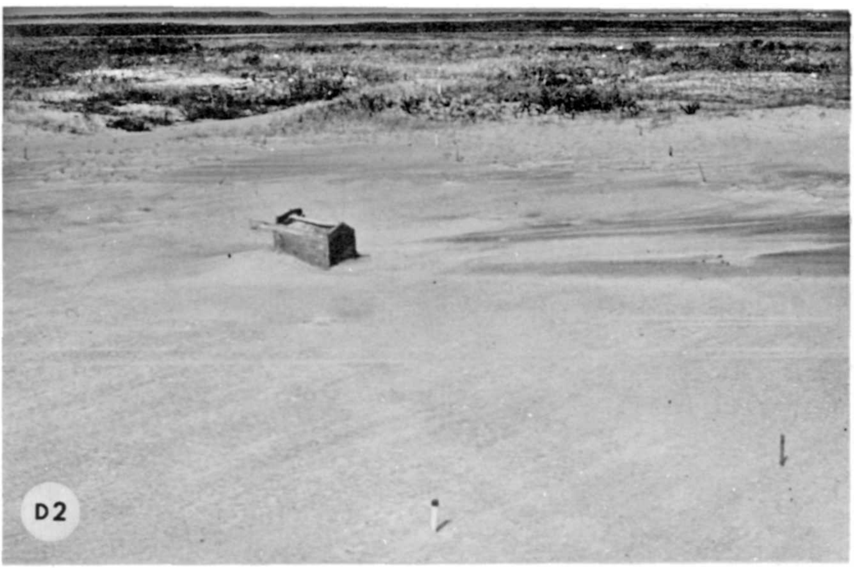
can be seen from the air, illustrating the ability of these islands to withstand storm surges. (*B1*) View toward the ocean end of the transect, with plastic pipe benchmark CC3 visible in the foreground. (August 1971.) (*B2*) After Ginger, fresh sand was pushed up over the beach, burying CC3 and covering the sea oat seedlings in the old driftline. The beach face was flattened and the berm crest moved back about 40 m, although the location of m.s.l. did not retreat. (*C1*) Close-up of benchmark CC3 before Ginger, August 1971. The shell





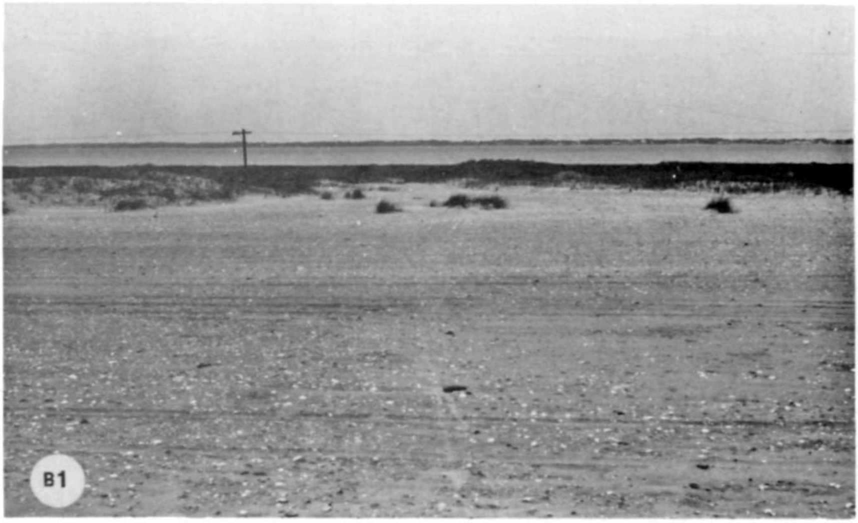
pavement on the island surface is readily visible in this view. (*C2*) Benchmark CC3 after Ginger. The sand level was raised 29 cm around this pipe. The deposits contain fine sand and shells, and the surface no longer has a shell pavement. (*D1*) View along the transect toward Codds Creek before Ginger, showing the line of benchmark pipes 30 m apart at which the cores shown in Fig. 27 were taken, and the general features of the overwash pass, dune system, and grasslands. CC4 is in the foreground. (*D2*) Transect 1 after Ginger. ➤



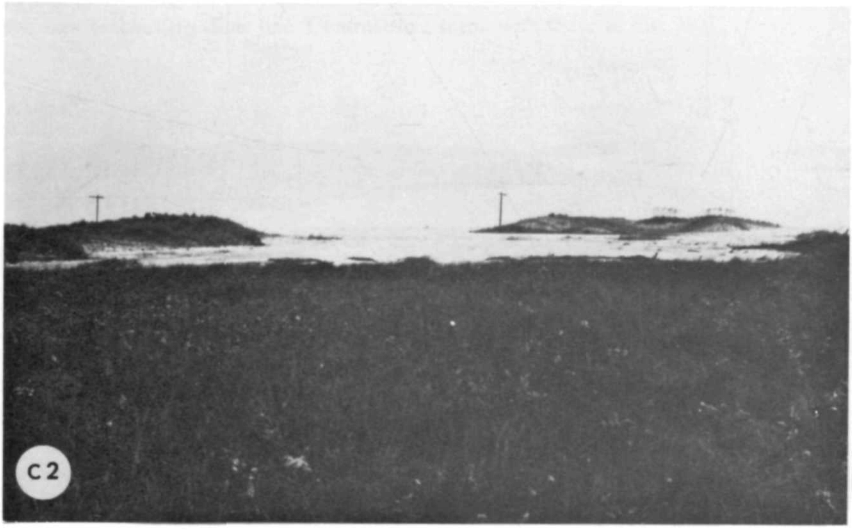


The drift line in dunes at the left shows that this area was totally submerged. The fine texture of the new deposit contrasts with the old surface. The sand surface at CC4 was raised 14 cm. At CC5 near the edge of the grassland it rose 19 cm, while at CC6, the third core back, which was in a hollow in the overwash pass, the level dropped 9 cm. At CC7, just visible in the distance, there was no change. The vegetation was unharmed by the storm surge, and only before and after measurements really show what occurred.

Fig. 29. Effects of Hurricane Ginger on Core Banks, where the storm crossed the Outer Banks causing heavy overwash just south of the Old Atlantic Coast Guard Station. (*A1*) View looking south of the berm and dune line in June 1971 (photo taken with a wide-angle lens). (*A2*) The same general area following Hurricane Ginger. The berm crest moved back and edges of the dunes along overwash passes were eroded. Even when the photo was ➤



taken in October, a new berm was building on the beach (photographed with a normal lens). (*B1*) An old overwash pass before Ginger – view is across the island from the view in Fig. 29 (photo taken with a wide-angle lens). (*B2*) The same area following Ginger. The dunes near the telephone pole were eroded, while the low dunes on the berm, seen as dark patches on the berm in Fig. 29, *B1*, were completely buried; just the culms of the grasses are visible ➤



(photographed with a normal lens). (*C1*) View across Core Banks toward the beach from the opposite side of the area in *B1* before the storm. (*C2*) Ginger left a major overwash deposit on what was once a grassland in a former overwash pass. (*D1*) The overwashed area in *C* as seen from a dune in June 1971. The grassland was relatively open, although patches of dense vegetation were present. (*D2*) After Ginger, the new sand at the end of

the overwash deposit was 50 cm (20 in) deep in places. Not all the grass was flattened; some *Spartina patens* is protruding from the sand. In a short time, the buried grass will recolonize the new surface as shown in Fig. 22. The view here is slightly to the left of that in *D1*; the telephone pole on the right in *D1* corresponds to the nearest pole on the left in *D2*.

Fig. 30. A tropical depression in the fall of 1970 crossed a stabilized section of Bogue Banks, with the results we have learned to expect on a stabilized barrier island. The beach was cut back considerably and the dune face badly eroded. Waves from the storm dissipated their energy directly against the dunes and what berm existed was cut away. High tide now reaches the dune line. Contrast this scene with those in Fig. 29.

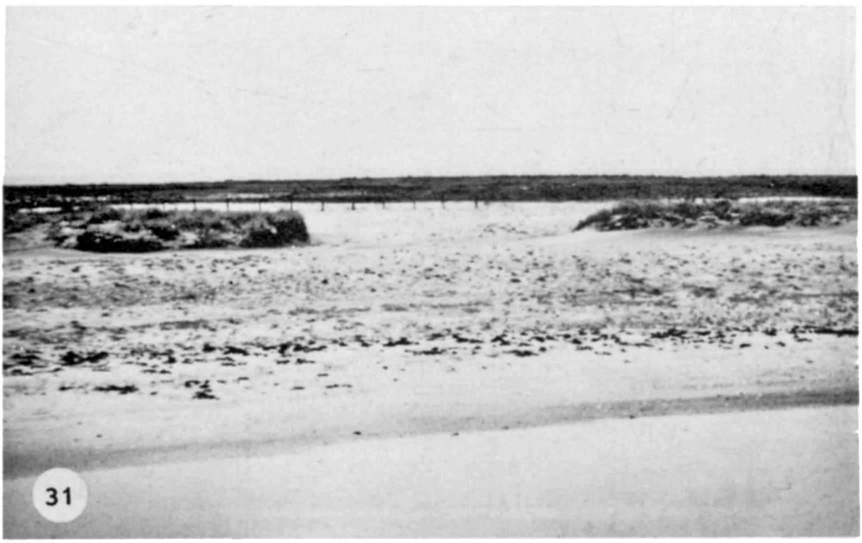


Fig. 31. The same storm drove water over the beach on Core Banks, with no damage except to experimental dune lines built with beachgrass on northern Core Banks; this straight dune line was continuous and storm surges piled up against it until a weak area broke through. Sand from the dune line was spread out in back as an overwash fan.

Fig. 32. Dune breaks and overwash caused considerable damage to cottages built too close to the beach. A storm on 28 March 1971 broke over the low dunes at Avon, a town within the boundaries of Cape Hatteras National Seashore, causing what is generally termed damage, although it was a predictable and natural event. (*Photo by* Cape Hatteras National Seashore Staff.)

Fig. 33. Tropical storm Doria, in August 1971, drove storm surges across Shackleford Banks. The dune line, while substantial, has breaks and passes. All along this beach, classic overwash fans were laid out between the dunes. The edge of this deposit was about 17 cm thick. (Telephoto view from a high rear dune appears to compress the distance between fan and ocean.)

Fig. 34. The same part of Core Banks as shown in Fig. 29, after Hurricane Ginger. The photographs in Fig. 29 were taken opposite the number "34." Contrast this view with Fig. 32. On the undeveloped beach, overwash builds up the inner part of the island. Past overwash deposits are clearly visible in this view. The area is just south of the view of the Coast Guard Station in Fig. 23. In December 1971, the Corps of Engineers cut a new inlet through the narrow neck near the top of the photograph. (*See* Fig. *10D*.)

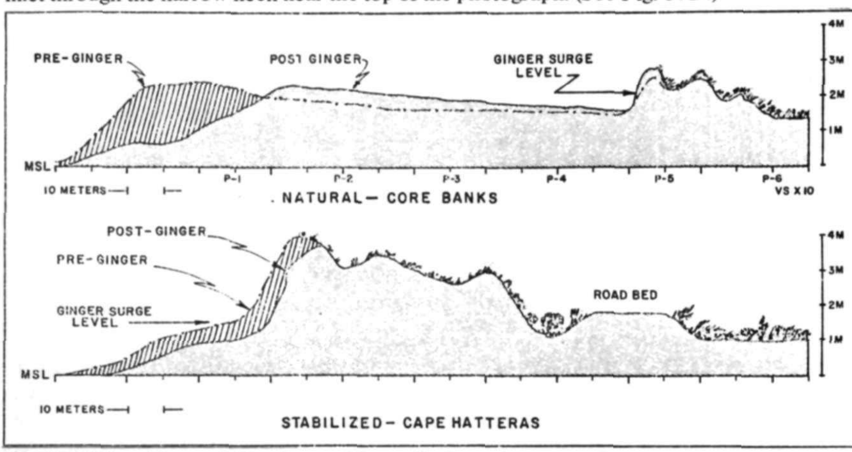


Fig. 35. The effects of Hurricane Ginger in Cape Lookout (Core Banks) and Cape Hatteras National Seashores are contrasted in this diagram from Dolan and Godfrey (in press). On Core Banks, the berm crest was knocked back, and the beach face flattened; overwash raised the backshore. Following the storm, the berm crest moved seaward and 10 months later all that was lost in the storm was eventually regained; see profile in Fig. 25 which shows the same transect in more detail. Dunes were actually raised by wind blowing the new sand into the dune line. On the stabilized section, the whole beach system was cut back, and the berm and dune line severely eroded, with the inevitable alarm and call for erosion control. The contrast between profiles of stabilized and natural beaches is in itself revealing.

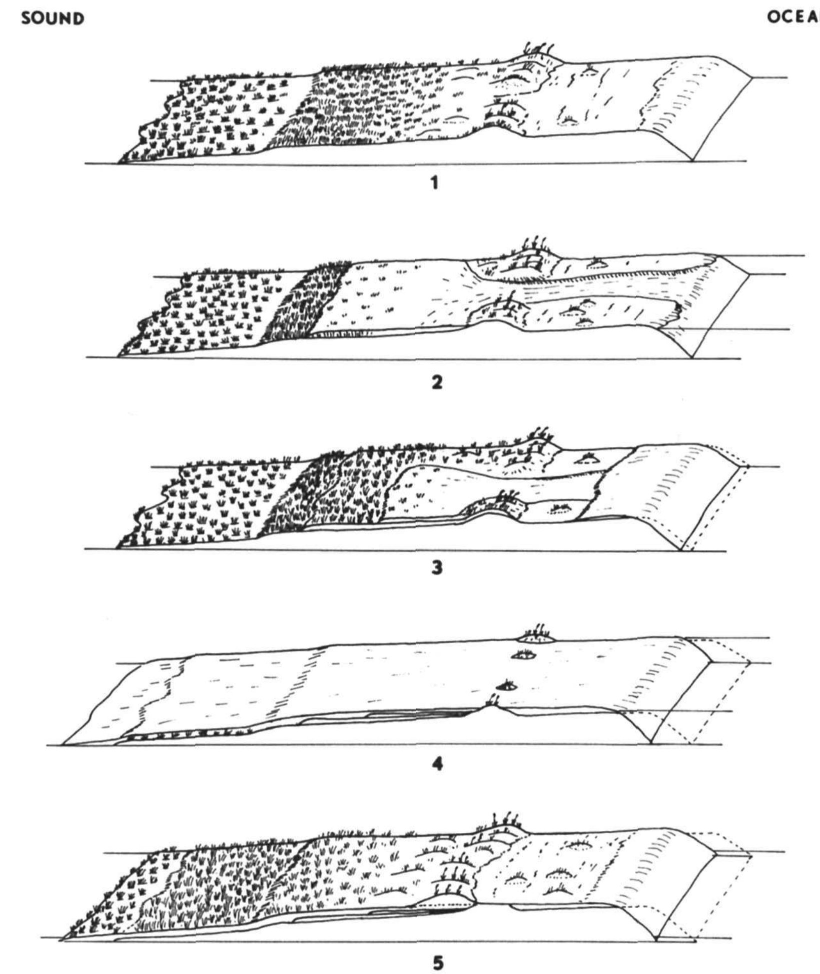


Fig. 36. Diagrammatic interpretation of the overwash process and recovery of a low barrier island such as Core Banks. (*From* Godfrey 1970.) (*1*) Cross-section of a low barrier island at any starting time. (*2*) A severe storm will push high tides over the beach berm; as the water flows back across the island it carries sand into the grasslands. (*3*) A second, less severe storm carries a smaller quantity of sand onto the earlier deposit. Abnormally high tides have pushed a little sand over the edge of the berm. Grass has pushed up through the earlier layer. The front of the island has retreated slightly. Following the storm, the berm will build seaward. (*4*) A severe storm inundates the island and adds a great deal of sand to the earlier layers. Old dunes have been knocked down and the sand spread out. The beach front has retreated substantially. In some places, the berm front may be lowered as sand is removed. (*5*) After a few years of relative storm quiet, the island surface has completely recovered, although the vegetation zones have been displaced slightly. Low salt marsh has grown up on the new base in the sound, the former low marsh has become high marsh, and the sand flat has extended into the old high marsh border.

alarm about the beach erosion shown by their measurements. The beach had indeed retreated markedly, but those measurements were made soon after a particularly severe storm period. Repeating some of their measurements shows the changes during the last 8 years (Fig. 37). It is quite evident that, for the most part, the beach has been prograding since those storms. (Measurements were made at about the same time of year to avoid seasonal differences.) Indeed, it appears that nearly all of the loss during the storms has been recouped. Nevertheless, based on measurements from old maps, Core Banks appears to be retreating about 50 m per century.

INLET DYNAMICS

Inlets, permanent or temporary, are an integral part of the barrier-island environment. Permanent inlets are usually opposite the mouths of major rivers and let river water into the sea. Temporary inlets shift position frequently, depending on storms and sand movement. Fisher (1962) described the historical patterns of both kinds of inlets on the Outer Banks and showed that nearly all the islands have been broken by inlets, even though only a few existed at any one time; 14 have been present at various times between Ocracoke Inlet and Barden's Inlet. Temporary inlets form when a storm first drives high water across an island. As the storm passes and the wind blows from the opposite direction, water in the sound is forced back over the island at low places, and may divide the beach on the way. Water can then flow back and forth until sand carried by the littoral drift eventually plugs the inlet. While the inlet is open, exchange between the sound and the sea benefits both ecosystems. The life of the new inlet depends on tidal flow, the depth of the sea and sound waters, the frequency of storms, and the amount of littoral transport. Broad shoals build up in the sound behind the inlet until they impede tidal scouring. The updrift side of the inlet usually migrates in the direction of the littoral flow while the downdrift side erodes. If migration of one side is faster than erosion of the other, the inlet eventually closes. The shoals behind are then invaded by salt marsh grass, and new marshes appear over a wide area that was once open water. Overwash and dune growth build up the new land and soon all superficial traces of an inlet disappear.

Such a pattern may be seen on Core Banks where Drum Inlet used to be. This inlet, opposite Atlantic, N.C., has had the usual history of opening and closing. It was open in the early 1800s and closed in the mid-1800s, only to open again in 1933 during the great hurricane of that year. It remained open until 1971, migrating southward nearly a mile, and building broad shoals in the sound (Fig. 38). The tides no longer

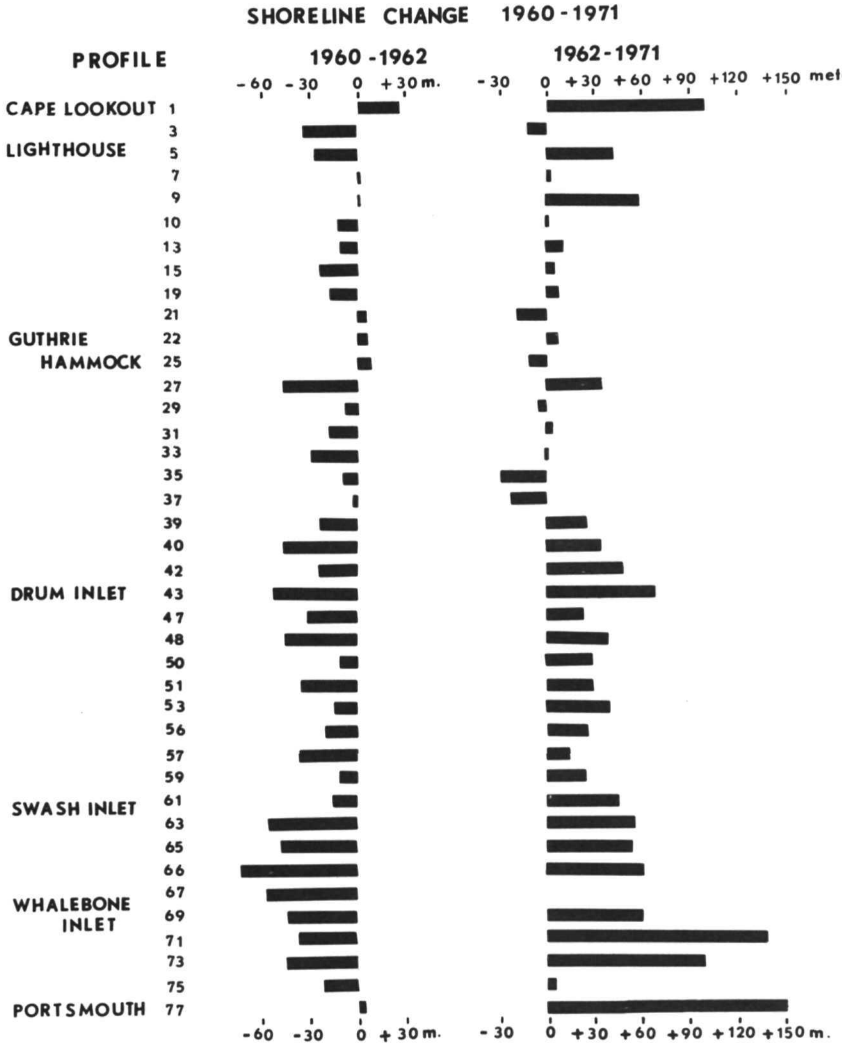


Fig. 37. Shoreline changes during the period 1960–71. The permanent benchmarks established by the Corps of Engineers in 1960 were used to determine beach retreat, and the data for 1960–62 are from their report urging erosion control (U.S. Army Corps of Engineers 1964). Measurements were made from the benchmark at each profile to mean sea level on the beach. In the early 1960s there were several severe storms, and such recession would be expected. The beach widths were remeasured in a similar manner during our studies and at the same time of year. Since there were few severe storms from 1962 to 1971, accretion predominated on most of the beach. Obviously, measurement of the width of undeveloped beaches means nothing unless one knows the storm frequency in the years immediately before.

regularly flooded these shoals, and small dunes started in the middle of the shoals where sand blown off the bare flats accumulated around sprigs of *Spartina patens* (Figs. 39, 40). The shoals are now being colonized rapidly by *Spartina alterniflora* (Fig. 41). (Fig. 41). Figure 44 is a map of the areas being colonized by plants and the locations of cores which demonstrate that the shoal material was definitely marine. In December 1971, the U.S. Army Corps of Engineers opened a new inlet about 4.5 km south of the old inlet and reestablished a regular tidal cycle in Core Sound.

Maps of the early 1800s and local documents show the site of Cedar Inlet a few miles south of the Drum Inlet area. By 1850, this inlet was completely closed, although its location was marked on the map (Fig. 45). We were able to locate Cedar Inlet (Fig. 42) and make several cores through three of the marsh islands in Core Sound behind the old inlet. The layers of peat were relatively shallow; underneath we found surf shells, so these marshes had their beginnings on shoals that formed when sand and shells from the beach were carried into the inlet. From the direct evidence of Drum Inlet and Cedar Inlet, with the patterns of marsh islands behind the barriers and the deep channels between these islands that end abruptly behind the barrier (Fig. 43), it seems clear that various parts of Core Banks contained inlets at one time or another (Fig. 46), and that the closing of inlets rapidly widens low barrier islands by a factor of 2 or 3. Overwash then fills in the low places, connects marshes as the island retreats, and continues the building process. Dunes constantly form, are knocked down, and then reform. Thus inlets, overwash, and dune growth are processes by which the barriers are built, maintained, and migrate as the sea rises (Fig. 46A). Much of what we see today on the Outer Banks is of very recent origin and definitely marine, even though the islands may have been formed originally by some other means. A stump we found in place on the seaward side of Shackleford, visible only at high tide, turned out to be less than 200 years old by Carbon-14 dating (Sample W-2307, U.S. Geol. Survey) (Fig. 14).

BARRIER-ISLAND VEGETATION

Because of limited time and space, the following discussions of barrier-island vegetation will be rather superficial and will be confined to the terrestrial communities. Obviously, marine communities surrounding the islands are of considerable importance; these will be dealt with in the future.

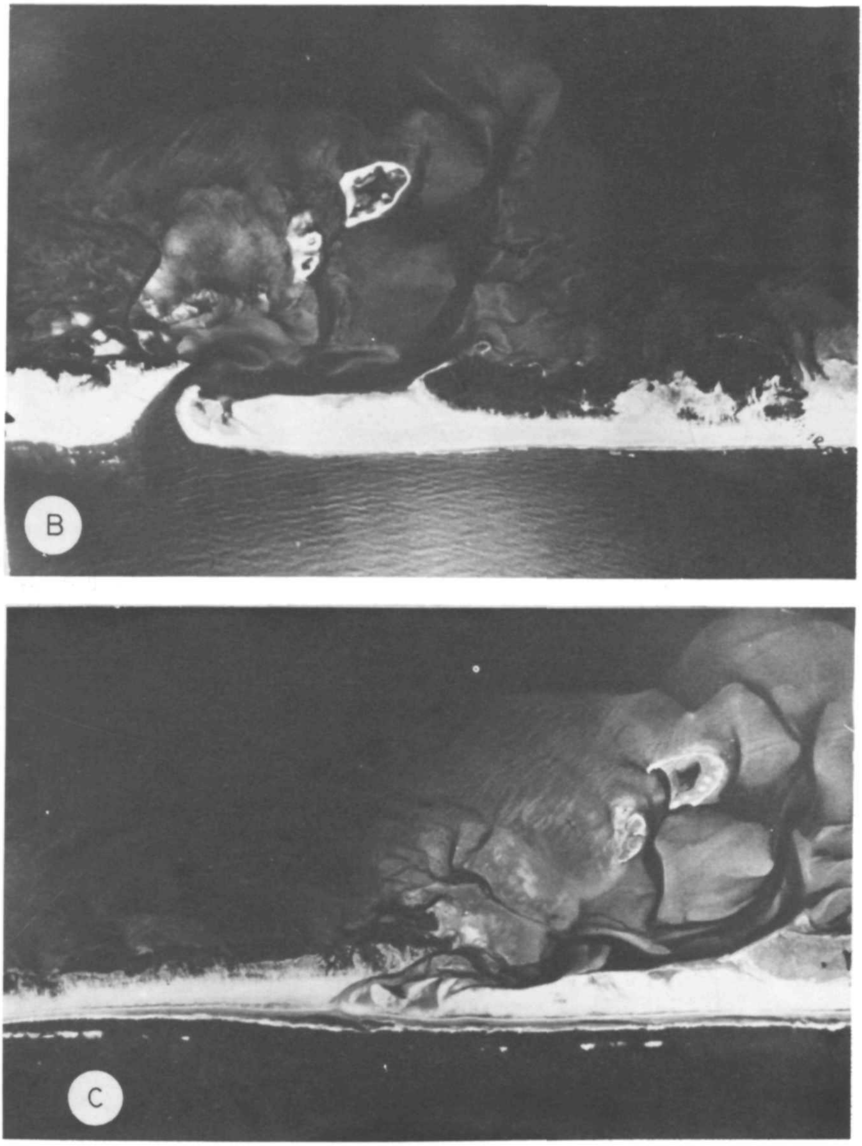
It should be noted that the systems described here are basically those of Cape Lookout National Seashore; the barrier islands to the north and

south of Cape Lookout vary from those discussed here, although there are certain basic similarities. Such variations will be described in future publications.

GENERAL ZONATION PATTERNS

The major ecosystems of the undeveloped, and to some extent of the stabilized, Outer Banks fall into five basic types: beach and berm, maritime grasslands, woodlands, fresh marshes, and salt marshes. Other types to be described result from various topographic conditions which modify or add to the basic five. A typical barrier-island zonation pattern

Fig. 38. Drum Inlet closing. (*A*) 28 October 1958. Drum Inlet was opened by the great 1933 hurricane and was then dredged from time to time. When this photograph was taken, several severe storms created numerous inlets which soon closed. Littoral drift is from the right to the left. A spit can be seen forming on the updrift side of the inlet; large deltaic shoals have appeared. Southwest is to the left in this photograph. (*B*) 24 August 1963. The updrift spit has migrated nearly all the way across the inlet. Tidal channels have become sinuous and shoals have continued to build. The downdrift side has been eroded.



Buried layers of marsh peat were exposed where the channel cut through the berm, as well as on the beach; this is further evidence of general barrier island retreat. (*C*) 11 February 1971. The updrift spit migrated faster than the downdrift side eroded, and finally sealed off the inlet in January 1971. Overwash began filling in the low areas behind the former channel. With the growth of the updrift spit, the inlet channel migrated 2 km southwest since 1958, following the normal pattern of inlet migration toward the south or west, depending on the orientation of the islands.

Fig. 39. View of Drum Inlet in June 1971, halfway down the spit which closed the inlet. Much of the berm is barren, although dunes are growing up along the backside. Dunes are well established where the spit is oldest. Beyond the old channel are broad shoals exposed at low tide. The towns of Atlantic and Cedar Island, North Carolina, are on the horizon.

Fig. 40. The older shoals associated with the Drum Inlet tidal delta are being invaded by *Spartina alterniflora* (in the foreground) and low dunes with *Spartina patens*, *Fimbristylis spadicea*, and *Erigeron pusillus* to the left. The broad, bare shoals provide sand for dune growth when they dry out at low tide.

Fig. 41. Large shoals behind the former inlet are being colonized by saltmarsh cordgrass, *Spartina alterniflora*, and blue-green algae, the dark patch in the foreground. In time, these shoals will become highly productive salt marshes. They are already heavily populated with fiddler crabs and are important feeding grounds for birds.

Fig. 42. Site of Cedar Inlet, open from the 1700s to the early 1800s. The marshes and creeks follow a pattern which suggests that they developed on former tidal delta shoals. Cores from these marshes showed peat layers about 50 cm thick underlain by fine sand and shells. The shells included the same surf species as were found in the Drum Inlet shoals, which is direct evidence that the Cedar Inlet marshes developed on sand and shells that moved down the beach in the littoral drift and then into the inlet, much as at Drum Inlet. When the inlet closed, marsh growth proceeded unhindered by tidal surges. The dark areas are underwater beds of widgeon grass (*Ruppia maritima*) and eelgrass (*Zostera marina*).

Fig. 43. Guthries Hammock seems to be located at a former inlet, although there is not yet any direct evidence for this. The former channel is probably the creek at the upper left. A migrating spit sealed off the inlet on the right side and a continuous berm built up. The dark patches are stands of live oak (*Quercus virginiana*), holly (*Ilex opaca*), and other forest species growing on old dunes. It seems likely that these old dunes may have started on barren shoals much like the present sequence at old Drum Inlet. In time the dunes were colonized by the tree species, thus culminating the successionary sequence from tidal delta shoals, to grassy dunes and marsh, to forest and marsh.

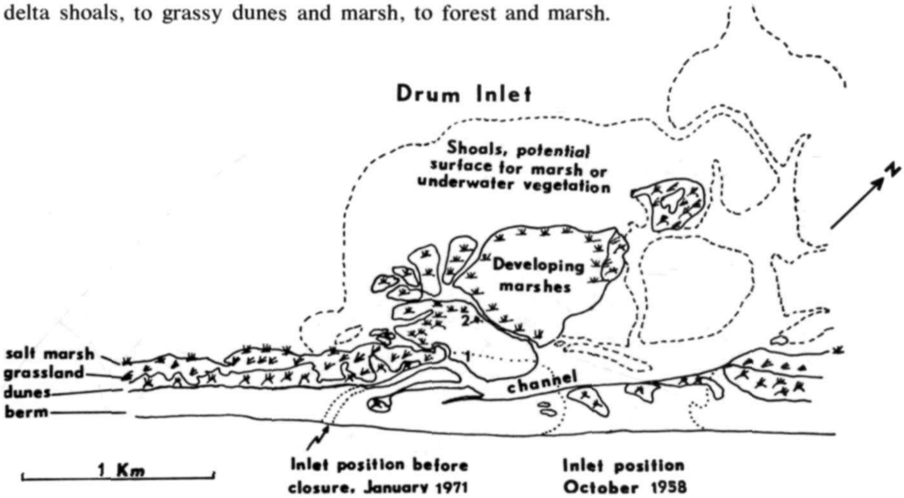


Fig. 44. Map of Drum Inlet, summarizing changes shown by aerial photographs and ground surveys. Figures 40 and 41 were taken on the large shoal nearest the channel marked by the number "2." Sites 1 and 2 were locations of cores containing surf shells. Marshes are developing all around the edges of the large shoals and completely covering the smaller ones. Shoals covered by low tide are potential substrate for underwater vegetation, such as in the Cedar Inlet area, and are being invaded by those species; a lush stand of eelgrass was found in the old channel near the letter "h." Inlets are thus a major means by which the barrier island system widens and large new salt marshes form.

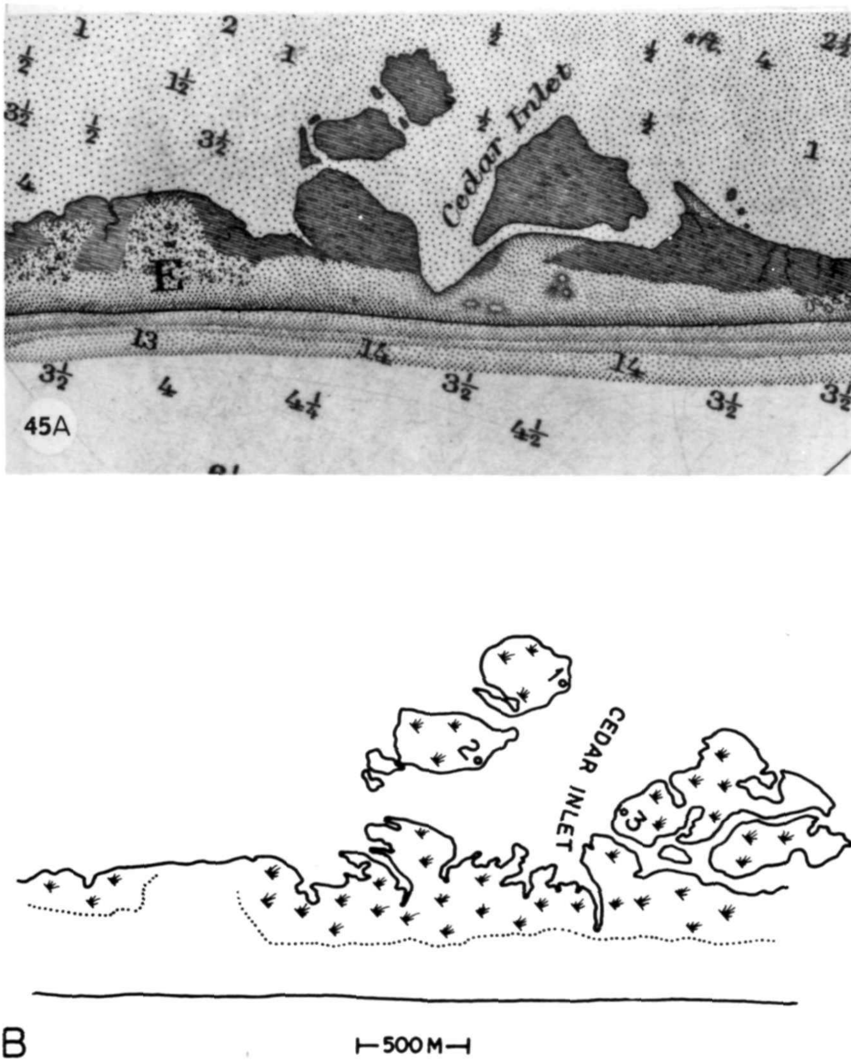


Fig. 45. (*A*) The site of Cedar Inlet as shown in the 1888 issue of the U.S. Coast and Geodetic Survey chart. The former channel is well marked on this map. (*B*) The present site taken from a 1963 aerial photograph. What was once the channel has been filled by overwash deposits. Numbers on the marshes refer to locations of cores described in Fig. 42.

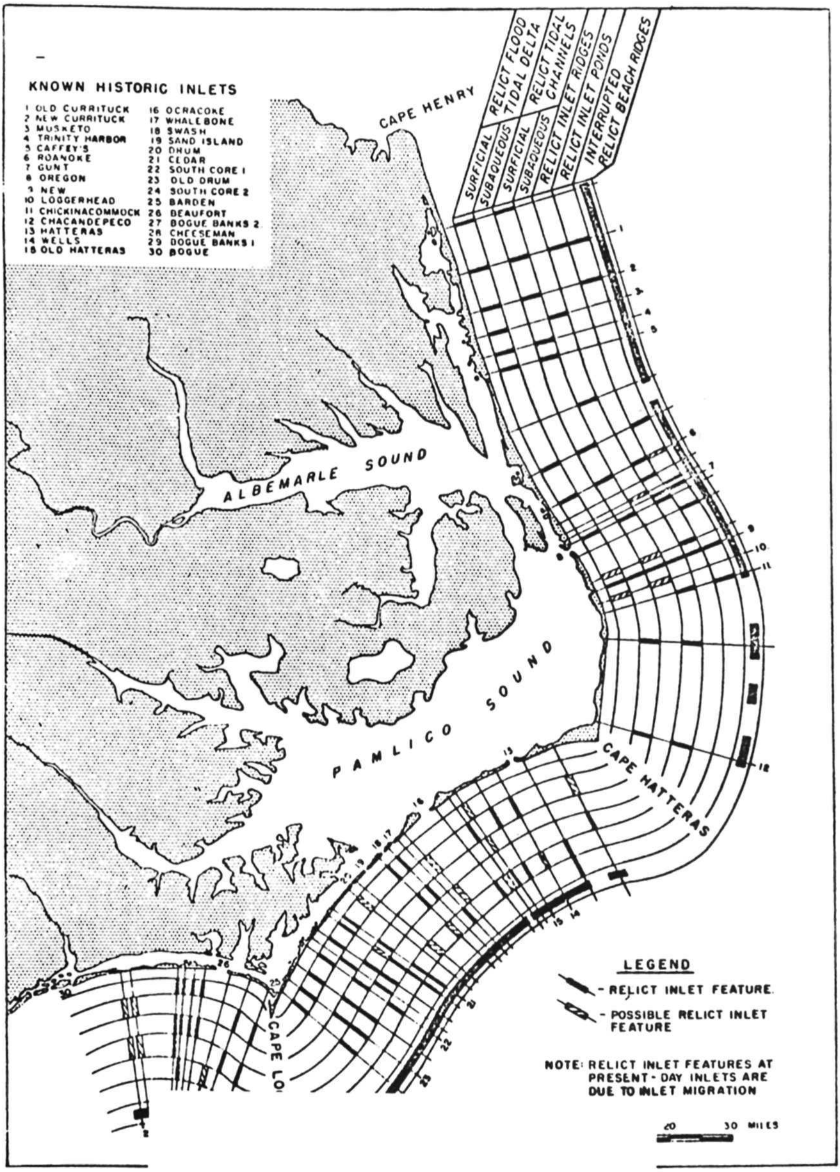


Fig. 46. Locat the Outer Banks. Inlet
features includ The patterns of salt
marshes and cı t and Cedar Inlet, sug-
gest that all suc ıt of the present barrier
island system c Seashore alone at least
23 sites, not cc features, were inlets in
historic times,

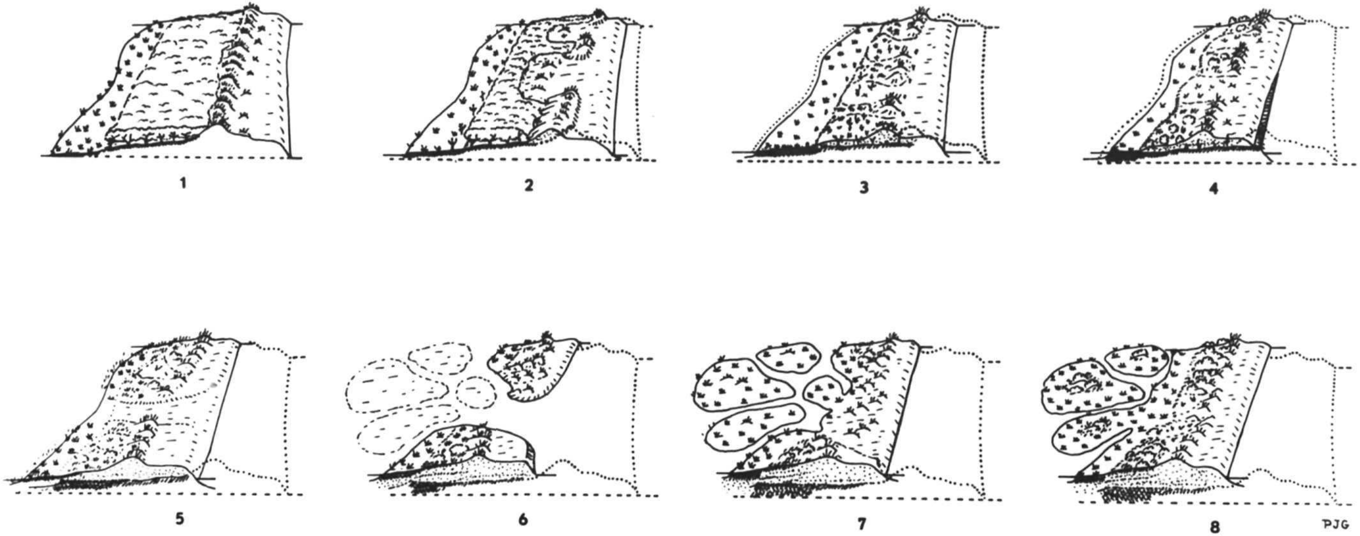


Fig. 46A. Generalized summary of barrier island dynamics and migration (vertical scale exaggerated). Stage 1 is a hypothetical barrier island which may have existed anywhere from present times to several thousand years ago, with a well developed dune line, or series of dunes, and a forest behind. In stage 2, the sea level has risen slightly and storms have knocked the dune barrier back into the woodlands. By stage 3, much of the barrier island has been overwashed and the dunes pushed back. The marsh has grown vertically and been somewhat eroded, and some former uplands are now salt marsh as a result of sea level rise. In stage 4, the barrier has retreated considerably from its original position. Dune and overwash sand has moved completely over the old forest, which is now exposed on the ocean side. Marshes near the island interior have been covered as well. Further retreat places sand completely over the original marsh surface and into the lagoon behind, where new marshes form. At stage 6 an inlet has opened and a typical tidal delta has appeared behind it. The temporary inlet has closed in stage 7, and the tidal delta now supports salt marsh and low dunes. Overwashes have tied the marsh islands to the main barrier and have filled in the old channels in stage 8. The salt marshes are now well developed on the old tidal delta, woods have grown up on the low dunes on these marsh islands, the salt marsh fringe behind the barrier is expanding, and on the barrier itself new dune lines and woodlands have formed where only a short time ago there was water.

can be seen at the Codd's Creek section of Core Banks, shown in Figs. 47 and 48. As one proceeds from the ocean side, the first zone is the bare berm and beach system, its width depending on island orientation, storm frequency, and human interference, as will be described later.

As shown in Fig. 48, the highest elevation of the island is generally the berm crest and the land slopes back from there. However, where dune building is active, elevations will be higher, but the berm crest remains a constant set by tides. The next zone is the dune strand, which may be of a very open and low type or more closed and higher, again depending on orientation to prevailing winds, storm effects, and human interference. Between and behind the dunes are extensive barrier flat grasslands on overwash deposits, with vegetation increasing in density and cover as one proceeds to the back side of the island. Such grasslands are dominated by a few species tolerant of flooding and burial.

In the more stabilized areas, a zone of woody plants appears between the grassland and the high salt marsh, usually as shrub thickets on the flats, but sometimes taking the form of maritime woodland on older dunes. Fresh-water marshes and ponds are frequently found between dune systems or in low areas on the barrier flats protected from tidal action. Such localized wetlands are most common where interdune slacks are well developed, such as on Shackleford. Perhaps the most extensive wetland system along most of the barrier island chain is that of the intertidal salt marshes which occupy low islands behind the barrier and form an intertidal fringe on the lagoon side of the barrier itself. The following discussions will deal with each type in more detail.

I. Bare Berm and Beach:

The most rapidly changing, semiterrestrial habitat is the sand beach within reach of high tide. This is no place for rooted plants or sessile animals; it is basically a detritus ecosystem populated by burrowing animals such as *Donax* (coquina), *Emerita* (mole crabs), interstitial amphipods and isopods, and feeding shorebirds. Primary productivity in the intertidal beach is limited to unicellular algae.

The berm environment is controlled in large part by the frequency of storms and is only slightly more stable than the beach itself. The vegetation is widely scattered; annuals, such as *Cakile edentula* (sea-rocket), *Amaranthus pumilus* (seabeach amaranth), *Salsola kali* (Russian thistle), *Euphorbia polygonifolia* (sea-side spurge), and *Polygonum glaucum* (seabeach knotweed), germinate most often from seeds in drift lines washed up during winter storms. The perennial beach grass *Uniola paniculata* (sea oats) also germinates in the drift lines and small dunes appear, which build until a storm either knocks them down or buries them. As for animals, shorebirds commonly nest on the berm, and the usually nocturnal ghost crabs scavenge in broad daylight on the relatively wild Core Banks.

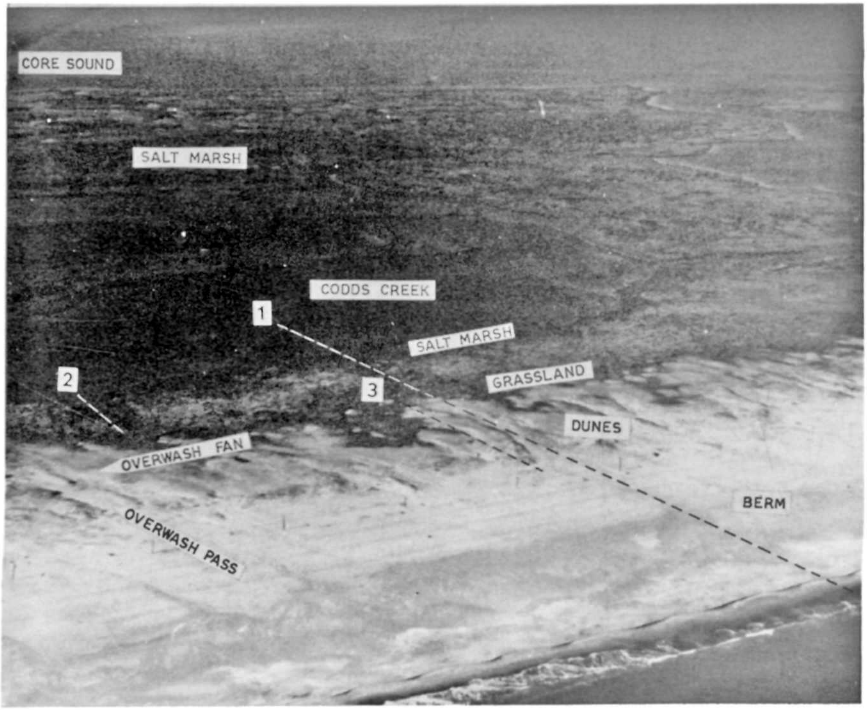


Fig. 47. Codds Creek study area, showing general features of a low barrier island and the zonation of its ecosystems. The dotted lines correspond to transects through an overwash pass and fan; the main profile, #1; overwash salt marsh, #2 and #3. Dunes are shown in Figs. 25 and 48, and the dunes and overwash salt marsh in Fig. 27. Darker patches in salt marshes are stands of *Junius roemerianus*.

The width and general nature of the beach-berm system vary considerably along the Outer Banks, and especially on those sections where artificial dunes have been built out on the original berm. The natural beaches typically have a wide berm zone ranging between 100 and 200 m, as shown in Fig. 49, which is rather consistent the length of the barrier. On those islands, such as in Cape Hatteras National Seashore, where dune lines have been built on the original berm, the width of the system is greatly reduced (Fig. 50). In some cases, where erosion is now a problem, the berm crest and backslope no longer exist and the high tide comes up to the dune (Figs. 52 and 54). In contrast to "stabilized beaches," the natural berms of Core Banks and Cape Lookout are wide and frequently reworked by storm tides (Fig. 51). In some sections, small dunes are developing on the berm (Fig. 53), but these are frequently knocked down or buried as storm tides wash over the berm

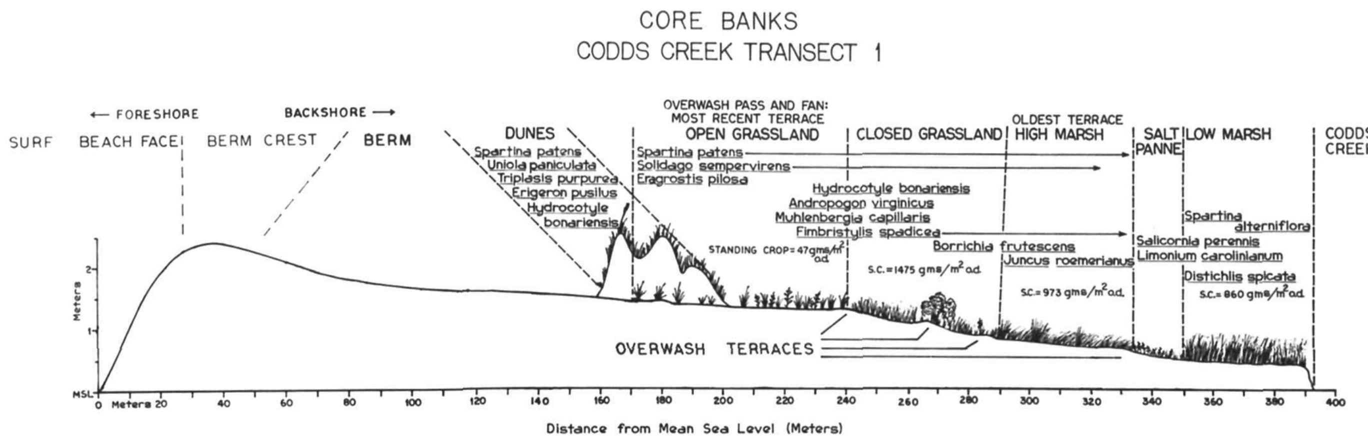


Fig. 48. Diagrammatic cross-section of ecosystem zonation at Codds Creek along Transect 1 in relation to elevation and distance from the beach. The vegetation is closely related to ages of overwash terraces and frequency of overwash. Species listed in each zone represent the most important members of that community (cover of 5% or more) and their relative positions along the transect, as determined in a 1-m-wide belt across the island.

Fig. 49. Aerial view up Core Banks just north of the Cape Lookout Lighthouse, showing the uniform width (about 150 m) of the berm on this undeveloped beach. The width is set by major overwashes and their frequency. The light color along the back of Core Banks is ice, a rare occurrence in these waters. Sand waves along the beach are visible near the top of the photograph. The dark gray (almost black) zone bordering the lighter gray in the center of the island is a dense shrubland, frequently found running between the salt marshes to the left and grassland and dunes to the right.

crest and across the island. Other stretches are duneless and wide (Fig. 55). The widest berm zones occur on Portsmouth Island, where the land slopes back across barren stretches of sand to the high-tide mark on the sound side (Fig. 56). Where the berm ends and the bare sand flats begin is hard to determine because the slope is very gradual. These broad, bare flats may be the result of overgrazing in the past, since vegetation is now invading certain portions, and dunes, marshes, and grasslands are developing. Further research is needed to decide to what extent the condition is man-caused.

II. Maritime grasslands:

Down the center of the Outer Banks run terrestrial grasslands of four basic types: barrier flats, dune strand, dune slacks, and mesic meadows. These grasslands combined occupy most of the supratidal land surface, and all four types intergrade with each other. The barrier flats are the extensive overwash terraces that characterize these banks, with dunes having formed on the terraces. However, where the islands are oriented across prevailing winds, the dune strand community predominates.

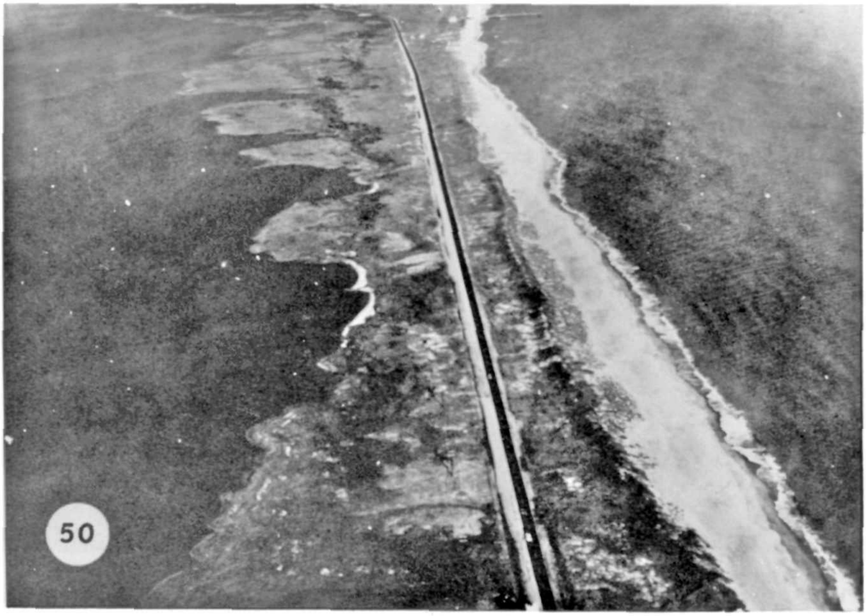


Fig. 50. The berm on developed beaches is narrow and irregular where it exists at all. The continuous dune line directly affects the width of the berm and prevents a normal berm development. The view is of Hatteras Island at Sandy Bay in Cape Hatteras National Seashore. (*Photo by* Cape Hatteras National Seashore Staff.)

Dune slacks are depressions between dunes, frequently formed by blowouts, the sand being removed down to the water table. Here, relatively mesic conditions and rich flora can be found. In contrast to the interdune slacks, yet similar in their mesic environment, are the low, flat, relatively rich meadows below the elevation of typical barrier flat communities, which are neither fresh-water marshes nor tidal flats. In general, these grasslands are maintained by environmental stress imposed by the oceanic environment: salt spray, overwash flooding and burial, moving sand, and ground water. Where such conditions are ameliorated by some means, the grasslands may succeed to woody vegetation.

a. Barrier flat grassland:

This vegetation type might be called an "overwash subclimax" because it is controlled by oceanic overwash. It is the predominant community on the flat, extensive overwash terraces that are typical of the low barrier islands. The grassland begins on the backslope of the berm, usually between the low open dunes, or even in front of dunes, and covers the flats behind the dunes. The general appearance of this com-

Fig. 51. Cape Lookout Lighthouse, built in 1859, showing the normal wide berm and dune line between the building and the beach. Storm waters are free to move right over the island and no erosion is apparent in the 113 years since the lighthouse was built.

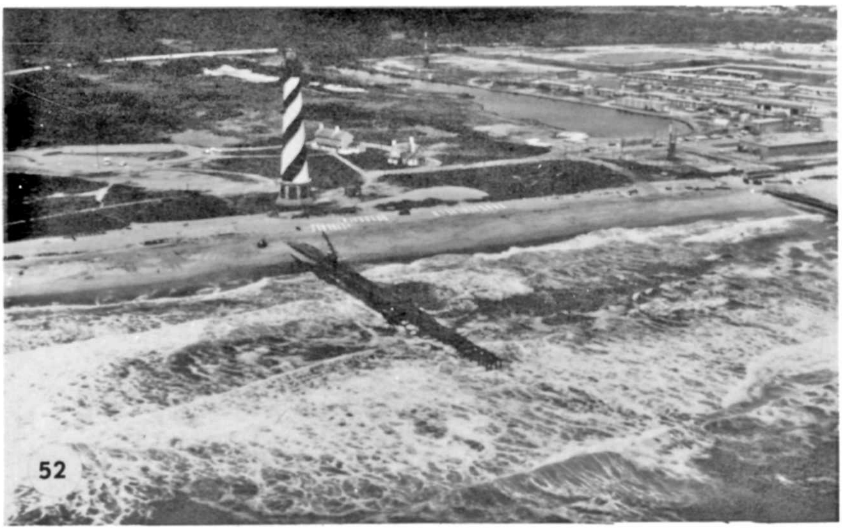


Fig. 52. The location of Cape Hatteras Lighthouse contrasts sharply with Cape Lookout. When this photo was taken 17 April 1970, the berm was non-existent. Groins under construction later caught sand, but caused other problems down drift. Storm waters are stopped at the dune line. In recent years much effort and money have been expended to keep the lighthouse from falling into the Atlantic Ocean. At Cape Lookout nothing at all has been done, yet that lighthouse is safe for the forseeable future. The artificial dune line clearly exacerbates the erosion problem. (*See* Dolan in press.) (*Photo by* Cape Hatteras National Seashore Staff.)

Fig. 53. Berm environment opposite Cape Lookout Lighthouse, largely bare although scattered dunes of *Uniola paniculata* are forming.

Fig. 54. Contrasting with Fig. 53 is the beach on Hatteras Island opposite motels in Buxton. The berm is gone and high tide nearly reaches the dunes. Storms have cut away the dune line dramatically and stimulated expensive beach nourishment projects.

Fig. 55. Much of the berm on Core Banks, here looking north with Guthries Hammock on the left opposite Davis, North Carolina, is barren and frequently overwashed.

Fig. 56. Vast reaches of Portsmouth Island are without dunes or vegetation (*See* Fig. 10F) and are therefore being lowered by wind and overwash. The remains of a ship are in the foreground, a small marsh island in the distance, and Portsmouth Village in the far distance. Some marsh vegetation is slowly invading the back side of Portsmouth Island between the established marshes.

munity is not unlike that of a Midwest prairie, stretching off as far as the eye can see. On many sections of the barrier islands, this flat grassland appears to be the only vegetation except for that of the low dunes and salt marshes. Its development and maintenance are controlled by salt spray, and more importantly, by overwash; the land is low enough to be flooded frequently and buried, so that plants here have a harder life than do those that grow on dunes. The overwash community begins on the back side of the berm, where a balance between wave action and deposition and plant colonization seems to be reached (Fig. 57). Storm waters regularly sweep down the berm slope and inundate this community, as evidenced by numerous drift lines in the grassland. The vegetation is well adapted to overwash burial and the rolling-over process by which the barrier islands retreat. As long as overwash operates, the ecosystem will persist for long periods; in this sense it can be considered an "overwash subclimax." The maritime barrier flat grassland is best developed on overwash terraces which grade together to form a flat surface. Dune strand vegetation can develop on these terraces as well, but only where enough sand has accumulated to raise the strand above the flooding level. Thus, the elevation of this community is set by the most severe storms of each storm cycle.

The barrier flat vegetation consists primarily of grasses, sedges, and a few forbs. Figure 48 shows a generalized cross section across a barrier island, with overwash-dependent zonation. Toward the berm, where flooding and burial are most frequent, is a generally open grassland dominated by *Spartina patens*, growing in scattered tussocks, with a low standing crop (generally less than 50 g/m^2 dry weight) and low cover (less than 20%). The vegetation becomes increasingly sparse approaching the berm slope. This is the zone where the ability of the grass to grow seaward and the regular overwash waves that keep the grass back are in conflict. During periods of relatively few storms, the vegetation migrates seaward only to be knocked back during storms. The open grassland grows on the most recent terraces, which are created or modified by regular storms. Growing with *Spartina* are scattered annuals, of which *Euphorbia polygonifolia* and *Cakile edentula* are the most common. Back from the berm zone, and in between the dunes, where overwash is less severe, the vegetation increases in complexity and biomass (Fig. 58). The *Spartina* is denser and is joined by *Solidago sempervirens* (seaside goldenrod) as a co-dominant. The major species of this vegetation type are resistant to salt spray (Oosting 1954) and salt-water flooding (Seneca 1969). The fact that they exist in zones here supports the thesis that such zones are more a function of overwash than of spray.

The open grassland extends back across the more recent overwash surfaces to the point where the elevation breaks and drops slightly to

Fig. 57. Open *Spartina patens* grassland on Core Banks at Profile 14, looking toward the ocean. The grassland has formed on an overwash pass and recent overwash deposits. Dark patches in the pass are driftlines from storm tides.

Fig. 58. The most recent overwash fan on Transect #1 at Codds Creek. This is the major terrestrial vegetation zone on these islands: broad grassy flats extending up and down the interior between dunes and marshes, open in the foreground, more closed in the distance. *Solidago sempervirens* and *Muhlenbergia capillaris* are seen with the dominant *Spartina patens*. The boards come in with overwash water.

the next terrace, deposited during the severe storms of the late 1950s and early 1960s; thus they are older terraces. A new, severe storm could overwash all of the existing terraces and create a new surface well back on the older layers. On these lower and older terraces the salt content is low, and the water table is near the surface. Here the open grassland grades into a closed community, with more than 50% cover and a standing crop of up to 1500 g/m^2. *Spartina patens*, *Solidago sempervirens*, *Eragrostis pilosa* (love-grass), *Fimbristylis spadicea*, *Muhlenbergia capillaris* (hairgrass), *Cynodon dactylon* (Bermuda grass), *Cenchrus tribuloides* (sand-spur), *Chloris petraea* (finger grass), *Gaillardia*, *Pluchea*, *Sabatia stellaris* (sea-pink), *Cynanchum palustre* (climbing milkweed), *Ipomea sagittata* (morning glory), *Spiranthes vernalis* (nodding ladies tresses) and other species share dominance (Fig. 59). The high standing crop and species diversity indicate that this is the most benign of the flat terrain habitats that are still subject to occasional sea-water flooding. Species from both the maritime grasslands and the high salt marsh mix in these closed grasslands. If the frequency of overwash and flooding decreases (as dunes build in the overwash passes, for example), shrubs such as *Iva frutescens* (marsh-elder), *Myrica cerifera* (wax-myrtle), *Baccharis halimifolia* (silverling), and *Juniperus virginiana* (red cedar) will form a shrub savanna or thickets. On the more protected sand flats, as well as on stabilized dunes and interdune sites, mosses can create thick carpets on the sand surface. The most common are *Trichostomium* sp. and *Barbula convoluta*. Other genera represented are: *Bryum*, *Physcomitrium*, *Funaria*, *Ephemeium*, and *Tortella* (J. Duckett pers. comm.). Hosier (pers. comm.) believes that the actual cause of the grassland zonation on these terraces is a result of variations in the level of the water table rather than overwash frequency, with the water being closer to the surface in the oldest terraces. Regardless of the exact cause, the zonation is the result of overwash.

The species that dominate these maritime grasslands are well adapted to sea-water flooding. In late August 1971, a near-hurricane passed over the Outer Banks. The storm surge drove water over Core Banks and through the transect area that had been carefully studied a few weeks before. The transect was reevaluated, and we found that of the 27 species tallied between the berm and the high marsh only 7, all annuals, were killed by the sea water; the perennials were not affected.

b. Dune strand:

Although the dune strand has received considerable attention from ecological researchers (Oosting 1954), little is known about the natural dunes of low barrier islands such as Core Banks. Most workers have been concerned with the causes of ecological zonation on dunes (Oosting and Billings 1942), or with ways to encourage the growth of grasses in order to build and stabilize dunes (Woodhouse and Hanes 1967).

Fig. 59. Closed grassland on the Codds Creek transect, primarily *Spartina patens*, *Hydrocotyle bonariensis*, *Andropogon virginicus*, *Muhlenbergia capillaris*, *Fimbristylis spadicea*, and *Borrichia frutescens*. Shrubs of *Baccharis halimifolia* are visible in the background. Dark stands of *Juncus roemerianus* mark the upper boundary of salt marshes.

Fig. 60. The beginnings of dunes on the open berm or bare sand flats are initiated by sea oats (*Uniola paniculata*) and *Spartina patens*. On more northern shores, American beachgrass (*Ammophila breviligulata*) takes the ecological place of sea oats. Year old seedlings of sea oats are concentrated in the driftlines. Seeds are washed up on the berm with other flotsam and soon buried. If conditions are right, they germinate readily and create curving lines. Sea rocket (*Cakile edentula*) is a common annual which also germinates in the drift lines and can be seen in the foreground.

The Outer Banks have three rather different dune systems, two of which are natural, the third man-made. Where islands are oriented across prevailing winds, high, relatively continuous and extensive natural dune fields exist. Where the barriers are oriented along prevailing winds, the dunes are low, open, and relatively scattered. Where stabilization programs have been in effect for several years, the dunes are in straight, continuous, and steeply sloped dike-like lines.

Dunes begin to form on the berm where seedlings of *Uniola paniculata*, *Spartina patens*, *Cakile*, and other plants take hold in drift lines or other locations (Fig. 60). The most important dune builder is *Uniola*, which requires burial and stratification to germinate (Wagner 1964). The drift which contains seeds acts as the first barrier to sand movement, and small dunelets form as sand is blown off the beach, berm, and overwash terraces. The first year after burial, seeds germinate and the seedlings begin trapping more sand (Fig. 61). By the second year (Fig. 62), the dunes become larger, as the *Uniola* trap more sand and grow upward through it. Within 4 or 5 years, dunes a meter or more in height can form, particularly where sand sources are readily available, such as well out on the berm or where the beach is at right angles to prevailing winds. If too far out on the berm (Fig. 63), the dunes will probably be destroyed by storms and the sand carried back by overwash. On islands oriented along prevailing winds and subject to continual overwash, the dunes are usually low and open, with numerous overwash passes (Fig. 64). Such dunes on Core Banks have appeared well back from the beach on overwash terraces created during the storms of the early 1960s. These dunes were formed, and are dominated, by *Spartina patens* and have grown to elevations of 1-2 m. Patches of *Uniola* occur on these dunes, and new dunes forming on the berm are primarily *Uniola* dunes. It is not clear why *Spartina* is the most common dune grass on Core Banks, since *Uniola* is dominant on Cape Lookout, Shackleford, and elsewhere. *Uniola* does, however, appear to be on the increase all along Core Banks. The vegetation of these low *Spartina* dunes (Fig. 65) is generally sparse; some of the species are *Triplasis purpurea* (sand-grass), *Erigeron pusillus* (fleabane), *Hydrocotyle bonariensis*, *Eragrostis pilosa*, *Physalis maritima* (ground-cherry), *Croton punctatus* (croton), and *Oenothera humifusa* (seabeach evening-primrose). *Spartina* is not as effective a dune builder as *Uniola;* it is not uncommon to find numerous dead *Spartina* plants, which appear to have died because sand was blown away from around their stems with resulting drought stress. *Spartina patens* has its best development where water is more readily available, such as the lower overwash terraces and high marsh, rather than in dunes. However, the most vigorous growth can often be found where fresh sand was carried onto a grassland by overwash or wind. In the

Fig. 61. Sea oat seedlings of the first year.

Fig. 62. By the second year, the sea oats are beginning to create small dunes on the berm, for which the open beach is a ready source of sand.

Fig. 63. In 4 or 5 years a major dune may form from what was a drift line. Dunes this close to the beach are usually knocked down by severe storms but the sand they contain is moved back into the island, not lost.

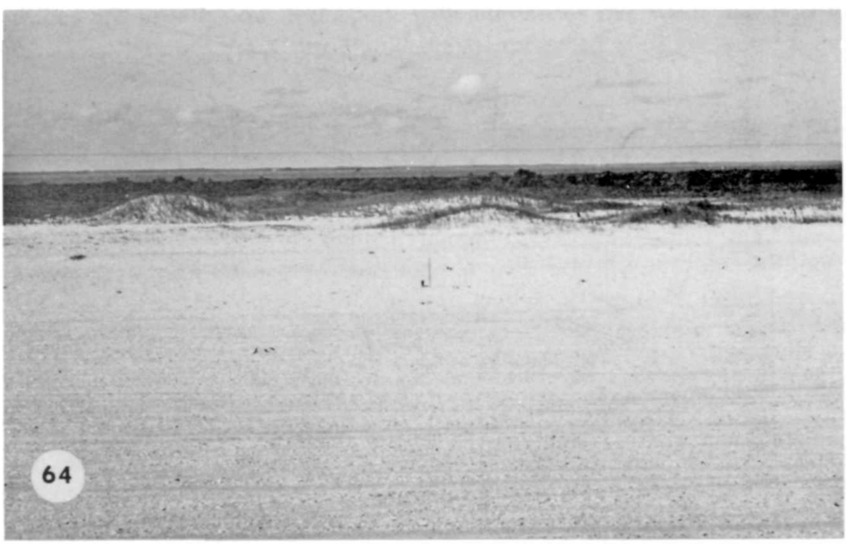


Fig. 64. The primary dune line on Core Banks is low because these islands are oriented in such a way that prevailing southwesterly winds blow sand off the beach rather than into the dunes. Overwash deposits between and behind the dunes are the source of material for dune growth.

Fig. 65. Close-up of *Spartina patens* dunes on Core Banks, with typical open vegetation. In this view the dunes are scattered, with overwash passes and flats between; there is no solid wall.

Fig. 66. Dune lines on Cape Lookout and Shackleford Banks are dominated by sea oats. Dunes grow tall here where the islands are at right angles to the prevailing winds. Even so, the vegetation is open on the first line of dunes, and numerous overwash passes break the continuity.

dunes, interdune flats, and grasslands, *Spartina patens* grows erect. In the high marsh, however, it tends to be decumbent, as it is in the northern part of its geographical range. These erect, dune-forming *Spartinas* seem to be primarily a southern phenomenon. Recent tests in the Duke University Phytotron have shown that *S. patens* contains both erect and decumbent ecotypes, even from the same island transect (Hosier pers. comm.).

The natural dune zones on Cape Lookout and Shackleford Banks, as well as Bogue Banks and Hatteras Island, are dominated by *Uniola* and are well developed along those sections of beach that are oriented across prevailing winds (Fig. 66). These dunes grow rapidly, and the *Uniola* shows a vigorous response as long as fresh sand continues to blow in on the grass. Under favorable conditions such as on accreting beaches, usually those on a lengthening spit or in other areas of deposition, or during relatively long periods of storm absence or falling or stable sea level, continuous dune lines can form. Under such conditions, the earlier dunes can become stabilized by the beach grasses, and other species will invade the dune as the conditions become more favorable. In such cases, one sees the appearance of the classical patterns of salt-spray zonation in dunes, as described by Wells (1939), Oosting and Billings (1942), and Boyce (1954). Spray-resistant plants such as *Uniola*, *Iva imbricata* (seashore elder), and *Cakile edentula* face the sea, while less resistant species such as *Andropogon scoparius* (broomsedge), *Parthenocissus quinquefolia* (Virginia creeper), *Erigeron pusillus*, *Heterotheca subaxillaris* (camphorweed), *Strophostyles helvola* (wild bean), and *Ampelopsis arborea* (pepper-vine) colonize the backslope (Fig. 69).

In contrast to the more restricted dune zone on Core Banks, the dune system on Shackleford Banks, which lies across the prevailing winds, is much more extensive. Here, the fore-dunes lie relatively close to the beach and are in a state of continual build-up. Like the Core Banks dunes, however, the Shackleford fore-dunes are a maze with overwash passes between the dunes (Fig. 65). Storm tides are thus free to sweep into the dune zone with little resulting damage to the dunes. Instead of expending energy on a single dune line, the waves roll through a maze of overwash passes, with energy loss occurring within the zone. The presence of tree stumps in the Shackleford dune zone indicates that this region was once forested, and, as discussed earlier, the evidence shows these were living trees in the 19th century (Fig. 67). Apparently, a well-developed dune line existed seaward of those trees, and storms of the late 1890s and early 1900s cut away the protecting stabilized dunes, so that wind and wave could begin moving the sand back into the woodlands. The retreat was well underway in the early 20th century, causing considerable alarm (Lewis 1917). Since then, the migrating

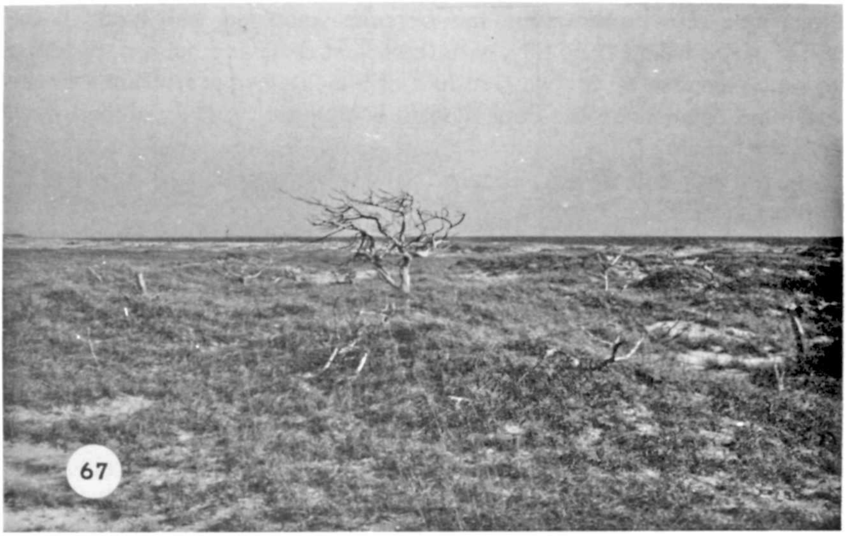


Fig. 67. Picturesque remnants of forest show through sea oats dunes on Shackleford.

Fig. 68. What was open, blowing sand in the early years of this century is now covered by sea oats with no help from man. In this view looking across Shackleford Banks, the remnant forest is visible, fronted by a new, stabilized barrier dune system.

dunes have become relatively stabilized by natural growth of *Uniola*, and a new rear dune system has become stabilized well back in the center of the island (Fig. 68), with the forest surviving behind this dune region. Overwash on the western half of Shackleford is restricted to the fore-dune zone, since the dune system is high and well developed back from the beach.

The eastern half of Shackleford, however, is more like Core Banks, and this may be due to a more rapid retreat of the island in that region. Where the dunes are well developed and succession is underway, the zonation typical of Bogue Banks (Fig. 69) may become reestablished on the western half of Shackleford. Already, the more stabilized sections have woody vegetation invading what were once moving dunes. Even though many migrating dunes have become stabilized through natural means, large areas of open, moving sand still exist on Shackleford and bear witness to the much more extensive dune movement of years past.

Where man has been more directly involved in attempts to stabilize migrating dunes, such as on the Cape Hatteras Banks, extensive dune dikes now contrast sharply with the natural dunes of Cape Lookout National Seashore. In the past, it was considered essential to prevent dunes from migrating; all available advice, including that from scientists, recommended dune stabilization for the health and survival of the Outer Banks. It is not surprising, then, that many projects, especially during the 1930s, were organized to build fences, plant *Ammophila breviligulata* (American beach grass), and stop the moving sand. The results of such projects, which have continued up to the present, are now evident in the Cape Hatteras region. There is no doubt now that dunes can be stabilized if so desired. A man-made dune line (Fig. 70) now exists all along the Cape Hatteras National Seashore, except in those areas where natural dunes were previously present.

Methods of building artificial dunes have been well worked out (Woodhouse and Hanes 1967; Savage and Woodhouse 1968) and are widely used. *Ammophila breviligulata* is planted by machine and heavily fertilized. It forms a dense cover, trapping all sand that blows into it, so that the resulting dune grows very high and has a steep backslope, since no sand gets over the top.

One difficulty that arises in the managed strand is that the grass suffers from fungus and scale attacks, which seem to be aggravated by the density of the grass and the fact that the Outer Banks are south of the natural range of *Ammophila*. The diseases are beneficial in one way; they make openings in the dense stands of beach grass and let in *Uniola paniculata*, the native dune grass of the Southeast, and other species which help change the managed dunes into a more natural strand community.

Another problem with the managed dunes is that they are so high and

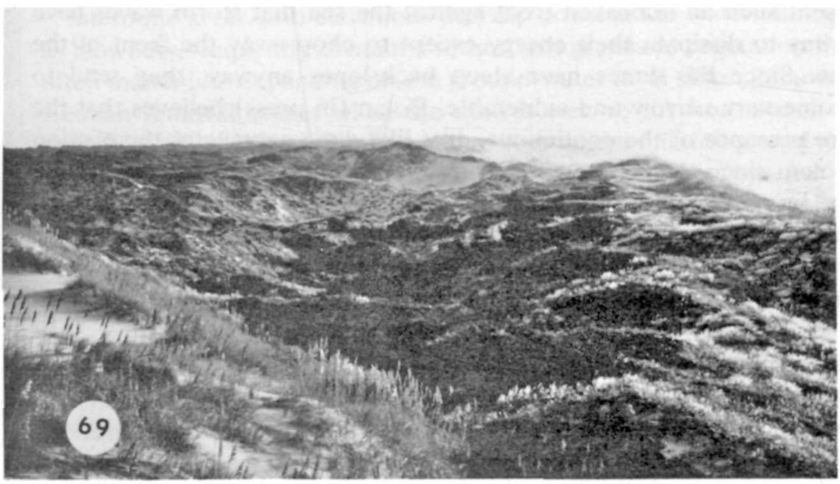


Fig. 69. These large, naturally stabilized dunes on Bogue Banks have so far not been destroyed by developers. Here, classic salt spray zonation patterns as described by Oosting and Billings can be seen. The foredune face and crest are dominated by salt-spray resistant sea oats. In the lee of the dunes, the less tolerant broomsedge (*Andropogon scoparius*) can survive (the white patches on the right). Shrubs grow in the low areas in the center of the photograph, and on the rear dune to the left, sea oats again dominates. Behind this dune is the maritime forest. Such a dune system has open areas and blowouts as well as great diversity of species.

Fig. 70. Continuous man-made stabilized dune on Hatteras Island, eroding on the seaward side. The American beachgrass is very dense due to heavy fertilization. The great density of vegetation on these man-made dunes is a distinctive feature of such stabilization programs and is not normally seen on natural dunes. There are few other species and no sand movement back of the dunes. Open areas in the grass are caused by disease and insect attacks. In such open areas, sea oats becomes established and lends a more natural appearance to the dunes.

present such an unbroken front against the sea that storm waves have no way to dissipate their energy except to chop away the front of the dune. Since the dunes have steep backslopes anyway, they tend to become very narrow and vulnerable. Dolan (in press) believes that the mere presence of the continuous, dike-like dune aggravates the erosion problem since the storm-wave energy is expended directly against the dune line rather than being dissipated over the island as on overwashed beaches with dune fields rather than lines. Waves crashing against the dune line cut away the base and the dune slumps into the water. Rebounding wave energy appears to further steepen the beach profile as the waves reflect back into the offshore zone. Other opinions suggest that the dune line is providing sand for beaches and in this sense is beneficial. Whatever the situation, those high, continuous dunes very close to the beach zone invariably are scarped and eroding, while those well back from the beach rarely show such effects.

The presence of stabilized dunes on the beach has also resulted in ecological changes behind the dunes. In those areas which once overwashed, the seaward dune line has allowed succession to proceed to such an extent that many areas now support shrub thickets rather than the open berm-zone or grassland community that previously existed. Vegetation more typical of the interior of these islands has migrated seaward with the protection against overwash and spray provided by the man-made dunes. Should such a trend continue, it is likely that plant communities will develop on the old berm that are not adapted to overwash. When the dune lines break, these communities may be obliterated completely and the normal return of overwash-adapted vegetation greatly delayed.

Natural dune-strand communities can develop on the berm, on overwash terraces, or on old inlet shoals wherever sand can be blown. The primary stresses in this habitat are moving sand and salt spray; other sources of stress are drought, lack of nutrients, and temperature fluctuations (Oosting 1954). However, the moving sand and the salt spray are also necessary nutrient sources, and where they are cut off by other dunes or by stabilization, the dune community declines. The way is then open for plants from the woodlands and thickets to invade the dunes.

Natural dunes have certain management advantages. The grass is sparse enough so that the sand can be moved by the wind, which keeps the dunes rounded rather than steep-sided; this shape is much better able to stand the physical forces of wind and wave. Dunes of this type are likely to migrate over other vegetation, but this is a necessary part of the dynamic stability of the islands. The natural dunes are also scattered about rather than in a solid wall, so storm waves flow between them and dissipate their energy gradually, without tearing everything down.

c. Dune slacks:

Interdune areas with elevations that dip down to the water table, such as blowouts, frequently contain a rather lush grassland vegetation that is often marsh-like depending on the ground-water level (Figs. 71 and 72). Aeolian removal ceases when the sand is wet, so the bottoms of dune slacks are usually level. Similar areas occur where migrating sand dunes have partially filled fresh-water marshes. These depressions are protected from salt spray and, if well within the dune zone, from overwash. They contain rather distinctive communities, with species from nearly all the grassland types, including marshes. The slacks are distinct from fresh-water marshes in that they tend not to have standing water during most of the year. In most cases, this grassland is dominated by *Spartina patens*, with important associates such as *Fimbristylis spadicea*, *Scirpus americanus* (three-square), *Andropogon virginicus* (broomsedge), *Dichromena colorata*, *Setaria geniculata* (foxtail grass), *Juncus megacephalus* and frequently *Juncus roemerianus* (black needle rush). Common herbaceous plants include *Hydrocotyle bonariensis*, *Bacopa monnieri* (water hyssop), *Polygonum glaucum*, *Commelina erecta* (dayflower), *Diodia virginiana* (button weed), *Sabatia stellaris*, *Lippia nodiflora* (frogbit), *Oenothera fruticosa* (sundrops), and vines such as *Mikania scandens* (climbing hempweed), and *Cynanchum palustre*.

d. Mesic meadows:

Somewhat similar in environment and vegetation to the dune slacks are the extensive, low flats that are close to the water table, yet not associated with dunes. Such flats are usually very old overwash terraces or old tidal deltas no longer in the intertidal zone, or they are protected by seaward dunes and have not been overwashed recently. These sites are common where islands are relatively wide, such as at Guthrie's Hammock (Fig. 84). Except for the forests, these low, moist flats contain the greatest number of plant species. Water is near the surface, and may flood the lower sections, especially following heavy rains. The vegetation on these protected flats is complex and contains species from all the other grassland communities other than characteristic dune plants or intertidal marsh species. The flats are rich in grasses, sedges, and herbaceous plants. In general, the floristic composition is much like that of the dune-slack community except that the vegetation is much more extensive and contains more species. The aspect of these meadows varies with the season; in late summer the dominance of grasses such as *Andropogon virginicus* is very evident (Fig. 87). The species of the dune slacks are found here along with several species of *Solidago* (goldenrod), *Gaura angustifolia*, *Lactuca canadensis* (wild lettuce), *Lythrum lineare* (loosestrife), and the creeping *Centella asiatica*. Grasses such as *Paspalum* and various species of *Panicum* are common. Invading these flats are shrubs, with *Baccharis* usually the most common.

Fig. 71. Low interdune slacks and blowouts that reach the water table are normally dominated by *Spartina patens*, but slacks protected from overwash and spray develop a rich herbaceous flora. There is frequently standing water in the slacks after heavy rains.

Fig. 72. Large interdune slack on Shackleford Banks with a herd of feral goats. Livestock grazing here can easily reach the water table by digging.

III. Woodland

Maritime woodlands and forests can be found in five general situations as shown in Fig. 73. Type 1 (behind a barrier dune) is the most common. Here, the forest vegetation is protected from some of the salt spray and sea-water flooding by a massive seaward barrier dune. Type 2 is generally found along beaches with relatively low wave energy. Here, the forest comes down to the primary dune zone, with thicket vegetation acting as a leading edge. Type 3 can be found on low barriers well back from the beach where dune building has not been significant. Such woodlands are generally termed "hammocks" and are protected from most storms by being on the back side of the island and having a leading edge that slopes down to the land surface. Major floods can reach and damage these low woodlands. Types 4 and 5 are again hammocks with slight variation. In Type 4 the woodland is on an island which may once have been part of an inlet delta or some other land form, but is separated from the main barrier by a tidal marsh. In Type 5, the forest may exist on small dunes or dune ridges that are part of the main barrier and separated from each other by fresh-water marshes, or they may grow on small islands that were once part of a tidal delta but are now connected to the main barrier. On barriers that form as spits, a cross section across the dune ridges would show the Type 5 profile, while a section along the dune ridge would be similar to Type 1.

a. Shrubland and Thicket

Woody vegetation can grow only where natural or artificial conditions protect the land from salt spray, sea-water flooding, and moving sand. Shrubland and thickets are seral stages on their way to becoming woodland, although these earlier stages can persist for a long time under the right circumstances.

Whenever there is a period of relatively little storm flooding, scattered *Myrica cerifera*, *Baccharis halimifolia* (silverling), and *Iva frutescens* spring up on overwash terraces and on the high marsh (Fig. 74). Since the high marsh is flooded occasionally, this land tends to stay in the open, savanna-like shrub stage; the three main species are fast growing and soon recolonize the marsh if they are killed off by a bad storm. On overwash terraces, as the seaward dunes continue to build up, and on the more stabilized dunes, the earlier arrivals are joined by *Juniperus virginiana*, *Zanthoxylum clava-herculis* (Hercules'-club), *Diospyros virginiana* (persimmon), *Ilex vomitoria* (yaupon), several woody vines, and eventually shrubby *Quercus virginiana* (live oak) (Fig. 75). In time, this vegetation becomes a thicket, and often a truly impenetrable tangle (Fig. 76). Therefore, open shrubland or savanna is typical of low areas, and thickets are found on higher ground such as stabilized dunes or well-protected flats.

On stabilized seashores such as Cape Hatteras, the shrubs and

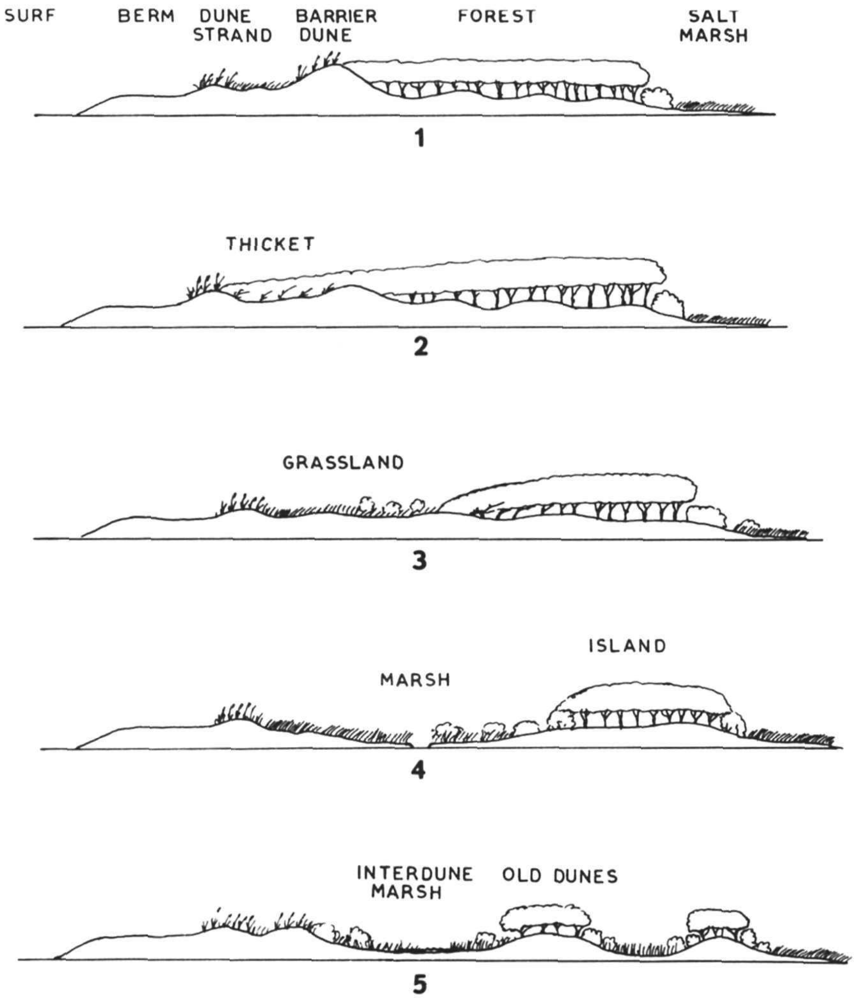


Fig. 73. Diagrammatic cross-sections of barrier island woodland types in the vicinity of Cape Lookout National Seashore. (*1*) Forest growing behind a high barrier dune, which may have migrated over some of the trees. (*2*) Forest with thicket extending out to first dune line (*3*) Forest with a sloping front and a thicket type of leading edge, separated from the dunes by grassland. (*4*) Forest on old dunes on the high part of a marsh island, separated from the main island by salt marshes. (*5*) Forest on old dune ridges, with interdune freshwater marshes and ponds.

Fig. 74. Shrub savannah on Ocracoke Island. Silverling (*Baccharis*) and myrtle (*Myrica*) are invading closed grassland.

Fig. 75. Closed shrubland on Shackleford Banks. Silverling, myrtle, yaupon (*Ilex vomitoria*), and red cedar are growing on overwash deposits on top of a former forest floor. (Taken in the dark area in the foreground of Fig. 77.)

Fig. 76. Densely tangled thicket on Shackleford Banks. Live oak (*Quercus virginiana*), red cedar, and yaupon and various vines are growing on stabilized dunes.

Fig. 77. Aerial view of the accreting west end of Shackleford Banks. Woodland of the types in Figs. 73–1 of 73–2 is growing on old dune lines. New dunes in the foreground show the same curving pattern as the older, stabilized dunes. Light gray areas in the woods are fresh marshes and ponds.

thickets have had a good chance to grow up. Miles of the "seaside highway" at Cape Hatteras pass through monotonous shrublands that handily block what vistas are left. This so frustrates visitors, as well as increasing the problem of insect pests, that the seashore management is actually taking steps to remove some of the shrubbery by cutting and burning.

b. Maritime Forest

The final stage in plant succession on stabilized barrier islands, that is, those sections of the barrier islands that are no longer under the direct influence of sea-water flooding or migrating dunes, is a woodland or forest. The term "maritime" refers to those woodlands that have developed under the influence of salt spray. Forests most similar to those on the mainland are thus on the most stabilized dunes and are protected from salt spray. Here, the trees which dominate the forest, such as live oak and loblolly pine, can attain heights comparable to those of mainland forests. At present only a few locations on the Outer Banks have an environment suitable for the survival of substantial woodlands. Good examples can still be found on the undeveloped portions of Bogue Banks (but these are rapidly being destroyed), on Shackleford Banks, around Ocracoke Village, in the Buxton area of Cape Hatteras, near the town of Avon, and in the Nags Head-Kitty Hawk region.

Maritime forests may be relicts from the time when rising sea level first isolated stabilized, wooded dune ridges from the mainland (according to the Hoyt theory of barrier-island formation). This seems to be the means by which the sea-island forests of South Carolina and Georgia were separated from the mainland, and may be the case for Bogue Banks (Burke 1962). New forests can grow up on recent land, such as an accreting spit, which Shackleford Banks appears to have once been, where the oldest dunes are stabilized and colonized by tree species. The Buxton Woods seems to have formed by a combination of processes not yet adequately explained. If dunes that develop on the shoals of old inlets grow high enough, they may be invaded eventually by woodland species and form hammocks. The woods at Guthrie's Hammock on Core Banks, Portsmouth Village, and Ocracoke Village seem to have originated this way. Where extensive overwashes have created wide terraces and a series of protective seaward dunes form, woodlands may develop as stability increases. Forest species may migrate along stable sections of the Outer Banks and then be cut off from older woodlands as the barriers migrate and change position. Rafting helps supply seeds for new woodlands; and many tree seeds, such as those of *Juniperus*, are carried easily by birds.

One of the best examples of maritime forest that has formed on old, curving dune lines can be seen on Shackleford Banks (Fig. 77). As men-

tioned earlier, a good portion of this forest was buried during the period of migrating dunes in the early 1900s. The remaining forest survives on dune lines that all curve across the island in the pattern characteristic of spit development. Wetlands of various kinds have developed between these forested dune ridges. Much of what was once moving sand dunes was stabilized by natural growth of sea oats (Fig. 78) and the living forest now survives as a remnant on the lagoon side of the new barrier dune system. That salt spray is a major factor in limiting the height of the forest canopy is evident in Fig. 79. Spray from the ocean side of the barrier dune has effectively sheared the top of the forest by killing the branches which reach upward beyond the elevation of the dune. In some places migrating sand dunes are still slowly burying the woodland and creating a new dune strand (Fig. 80). The interior of the maritime forest reflects both the effects of spray and the otherwise generally good growing conditions. Branches are relatively low to the ground and the vegetation is often a dense tangle of vines and tree limbs. *Tillandsia usneoides* (Spanish moss) as well as many epiphytic lichens are common on the tree branches (Fig. 81). The usual appearance of *Quercus virginiana* is shown in Fig. 82. While the trunk may be quite thick, the tree itself is low, with large limbs near the ground. The forest environment contrasts sharply with that of the dune strand. Here there is deep shade and less wind, and plants grow here that could never survive the open dune strand. The reduction of wind and the heavy vegetation make the forest a most unpleasant place for humans during the insect and tick season. Where extensive forests have developed on wide sections of the Outer Banks, such as Buxton Woods, the forest trees well back from the beach look no different from those on the mainland. In such places, straight, tall *Pinus taeda* (loblolly pine) are common and show little sign that they are on a barrier island.

The Outer Banks maritime forest is dominated primarily by *Quercus virginiana*, along with *Pinus taeda* and *Juniperus virginiana*. In addition, *Zanthoxylum clava-herculis*, *Quercus phellos* (willow oak), *Q. laurifolia* (laurel oak), *Carpinus caroliniana* (hornbeam), *Ilex opaca* (American holly), *Persea borbonia* (red bay), *Osmanthus americanus* (wild olive) and *Cornus florida* (flowering dogwood) are common species in the barrier-island forest. In certain forests, such as the Buxton Woods, *Pinus taeda* is a most significant member of the forest community well back from the beach. Toward the beach, the more salt-resistant oaks are most important.

Besides the *Tillandsia usneoides* that drapes the limbs of trees, lianas commonly thread the trees together and tie them to the ground, frequently in dense tangles. These vines are mostly *Smilax* spp. (greenbriar), *Parthenocissus quinquefolia, Vitis rotundifolia* (muscadine grape), *Ampelopsis arborea*, *Berchemia scandens* (rattan-vine), *Gelsemi-*

Fig. 78. General view of Shackleford forest behind the barrier dunes. Open area on left is a salt march connected with the sound.

Fig. 79. Close-up of the leading edge of the same forest. Salt spray prunes any tree which grows up above the level of the sheltering barrier dune.

Fig. 80. Many of the dunes on Shackleford Banks are stable now, but this one is still moving into the forest. Such a scene was more typical in the early years of this century.

Fig. 81. Interior of the Shackleford forest, with short live oaks and red cedars, vines (*Vitis*, *Rhus*, *Smilax*), and Spanish moss (*Tillandsia*).

um sempervirens (yellow jessamine), and *Rhus radicans* (poison ivy). Shrub species below the forest canopy include such plants as *Callicarpa americana* (French mulberry), *Ilex vomitoria*, *Myrica cerifera*, *Rhus copallina* (winged sumac), *Morus rubra* (red mulberry), and *Sabal minor* (sabal palmetto) in scattered locations up to Buxton Woods.

Herbaceous plants on the forest floor are rather sparse and include such species as *Uniola laxa* (spike grass), a relative of sea oats, *Stipa avenacea* (black oat-grass), *Mitchella repens* (partridge berry), *Bidens bipinnata* (beggars ticks), *Elephantopus nudatus* (elephant's foot), *Lepidium virginicum* (poor man's pepper grass), *Cnidoscolus stimulosus* (spurge nettle), and various species of *Panicum* (Au 1969).

In addition to the epiphytic *Tillandsia usneoides* and vines, *Polypodium polypodioides* (resurrection fern) can be found on the tree trunks, as well as the parasitic *Phorandendron flavescens* (mistletoe). But often even more conspicuous than these higher plants are the many species of lichens which cover the branches of trees. One of the most striking is the bright orange, profusely branched *Teloschistes flavicans* (golden lichen); another is the grayish-green *Usnea strigasa* (old man's beard), and also the yellow-green, finely branched *Ramalinas*. Besides these branched lichens are the leafy, gray-green *Parmelia* and the smaller, whitish blister lichen *Physcia*. The most conspicuous lichen that forms a crust on the trunks of trees, particularly *Ilex opaca*, is the bright red *Lopadium leucoxanthum* (Au 1969). The most common lichens found on the ground are *Cladonia cristatella* (British soldiers), and other species of the grayish, finely branched *Cladonia* lichens generally called "reindeer moss."

Figure 83 shows an example of the Type 2 woodland where woody vegetation extends from the maritime forest down to the fore-dune line. Here the low dunes and the thicket vegetation act as the leading edge of the forest, causing spray to be carried up and over the forest canopy. Such a profile can exist only where the dunes are still relatively stable and intact. Once storms break the fore-dunes, the woodland is subject to burial, flooding, and salt-spray damage. A large, hammock-type forest is shown in Fig. 84, Guthrie's Hammock. The ocean lies to the left of the hammock in Fig. 84 and to the right in the closeup in Fig. 85. Here, the woody vegetation slopes down to the general level of the barrier flat with no dunes in front. The aerodynamic leading edge has thus been formed by salt-spray pruning, and the trees are taller as one proceeds into the hammock from the seaward side. Figure 86 shows a typical small hammock on an island behind the Outer Banks.

Certain hammock areas take on the aspect of a savanna vegetation such as shown in Fig. 87 near Guthrie's Hammock on Core Banks. The oaks are growing on small, old dunes that are only slightly higher than the surrounding flats of marsh and mesic meadow vegetation. Such areas bear more resemblance to the savannas of Africa than to the

maritime forests of the Outer Banks.

Interesting and varied though it is, and containing numerous plant and animal species, the maritime forest is really not adapted to the rigorous conditions that prevail over most of the Outer Banks today. Indeed, less than 20% of the surface area of the Outer Banks can be considered woodland, and this small proportion has not changed significantly over the past century, except for localized situations. Trees can only survive on the most mesic sites on the islands, where either dunes or distance protect them from moving sand, sea-water flooding, and salt spray. The best developed forests are limited to a few sections of the Outer Banks that have had a long history of dune building and general accretion, most notably where the beaches lie across prevailing winds. Most other areas of the Outer Banks have hammock-type forests located well back from the beach on old tidal delta deposits or extensive old overwash surfaces.

Slight changes in environmental conditions can eliminate woodlands, as has been seen in various locations where storms or other stresses broke the leading dune lines and sand began burying the forests. Where trees are protected they can grow rather rapidly. The growing season is long and water and nutrients (primarily from salt spray) are adequate to produce trees of 30 cm dbh in 50 or 60 years. The oldest tree we found was a hundred-year-old cedar; some *Quercus virginiana* may be older but their centers are usually too rotten to sample with an increment borer. One possible reason for the claim that ancient trees exist on the Outer Banks is that coastal trees frequently have "false rings," which form during drought or heat stress, in each annual growth increment. Without a microscope, a casual counter of rings in a cut tree would be likely to count these false rings. In some cases, as many as five or six false rings can be found in a single season's growth, leading one to think that a relatively young tree is very old.

IV. Fresh Marshes

Fresh-water marshes are limited on the Outer Banks. They are usually found on islands such as Shackleford Banks, Bogue Banks, and Hatteras, where spit growth has resulted in curving lines of dunes; the depressions between the dunes are cut off from the sea and turn into fresh marshes (Fig. 88). Other fresh-water habitats, such as Mullet Pond on Shackleford, are formed when sand bars or spits build across the mouth of a small bay (Fig. 89). These ponds and marshes often dry up when rainfall is low, but when they are full, they support a wealth of birds, amphibians, small fish (in permanent ponds), and are characterized by marsh plants such as *Typha latifolia* (cattail), *Typha angustifolia* (narrow leaved cattail), and *Cladium jamaicense* (saw grass); also *Andropogon virginicus*, *Juncus roemerianus*, *J. megacephalus*, *J. coriaceus*, *Setaria geniculata*, *Kosteletzkya virginica* (seashore mallow),

Fig. 82. Large live oak in the same forest. Because of the salt spray the trees grow low with heavy branches near the ground.

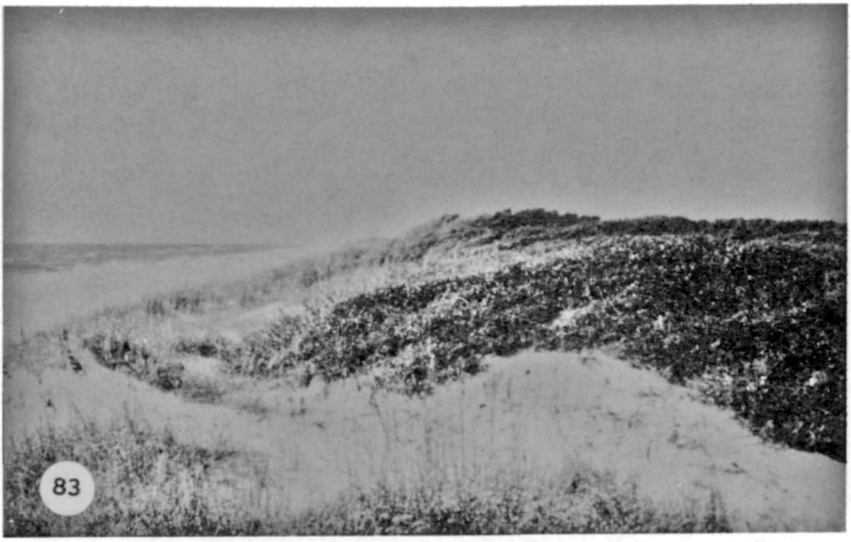


Fig. 83. Bogue Banks, leading edge of a forest of the type in Fig. 73–2. The thicket extends from the forest out to the first dune line; this may have been the typical pattern on Schackleford Banks in the late 1800s.

Fig. 84. Guthrie's Hammock, on Core Banks opposite Davis, North Carolina, with woodland of the type in Fig. 73–3, well back from the beach. The ocean is to the left. (Isolated stands of trees are locally called hammocks.)

Fig. 85. Leading edge of Guthrie's Hammock woods, the trees sloping to the ground.

Fig. 86. Hammock on a marsh island as in Fig. 73–4, Bogue Sound.

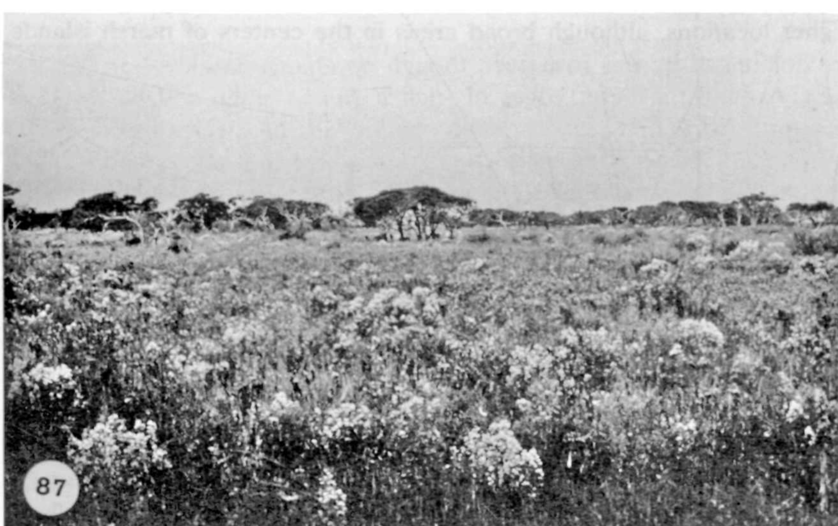


Fig. 87. Savannah as in Fig. 73–5, in the vicinity of Guthrie's Hammock. Live oaks on low dunes are surrounded by a rich closed grassland and marsh system. The flowering shrub is *Baccharis*.

Sagittaria latifolia (arrowhead), *Boehmeria cylindrica* (bog-hemp), *Hydrocotyle umbellata* (water pennywort), *H. bonariensis*, *Ipomea sagittata*, *Mikania scandens*, *Dichromena colorata*, *Scirpus americanus*, *Fimbristylis*, *Cyperus*, *Spiranthes vernalis*, *Pluchea*, *Bacopa*, *Cicuta maculata* (water hemlock), *Lippia*, *Centella*, *Chara* (stonewort), *Ludwigia* (false loosestrife), *Polygonum* (knotweed), *Paspalum floridanum*, *Cyperus*, *Eleocharis* (spike rush), *Samolus parviflorus* (water pimpernel), ferns, and many other species.

V. Salt Marshes

Salt marshes blend so gradually into the maritime grassland that it may be difficult to find the boundary. The marshes form on the lowest terraces, which are flooded by tides from the sound. There are two basic categories—high marsh and low marsh. The high marsh is where *Spartina patens* reaches its best development, with *Fimbristylis spadicea* as co-dominant; here the standing crop is up to 970 g/m^2 and the ground cover is 100%, with *S. patens* accounting for 30% (Fig. 90). The high marsh is distinguished from the low marsh by being flooded only during spring or storm tides, and then usually only to a depth of a few centimeters.

In addition to the *Spartina patens-Fimbristylis* type of high marsh vegetation, broad expanses are dominated by *Juncus roemerianus*, which, once established, aggressively crowds out everything else (Fig. 91). It withstands fresh and brackish water and normally is found in higher locations, although broad areas in the centers of marsh islands are dominated by this rush even though no change in elevation can be seen. Around the outer edges of such a *Juncus* stand will be the low marsh of *Spartina alterniflora*. The relation of this species to the other salt-marsh types is not well known at present, but it can apparently invade a *Spartina* marsh and eliminate the cordgrass, particularly where tidal inundation has become irregular.

The edge of the *Spartina patens-Fimbristylis* vegetation usually marks the beginning of the "low marsh" dominated by *Spartina alterniflora*, flooded by daily tides. Between these two zones there are often "salt pannes" (Fig. 92), depressions where salt water accumulates, evaporates, and creates a highly saline habitat, dominated by halophytes such as *Salicornia* (glasswort). The low marsh is a generally uniform community of *Spartina alterniflora*, with a little *Salicornia*, *Distichlis spicata* (spikegrass), and *Limonium carolinianum* (sea lavender) mixed in. The productivity of the low marsh varies with its elevation; much of it is often just within reach of the tides, and here the grass is relatively short, with a productivity of around 800 g/m^2 and a rather low standing crop (Fig. 93) If the edge of the marsh slopes gradually to the sound bottom, there is a zone where the grass grows luxuriantly, with high productivity near 2000 g/m^2 (Fig. 94). However, this tall grass strip is

Fig. 88. Fresh water marsh on Shackleford, between the wooded dunes in Fig. 77 with arrowhead (*Sagittaria*), cattail (*Typha*), blackneedle rush (*Juncus roemerianus*), morning glory (*Ipomea*), and marsh mallow (*Kosteletzkya*).

Fig. 89. Mullet Pond on Shackleford, with narrow-leaved cattail (*T. angustifolia*). This fresh pond was part of the sound in the last century until a bar developed across its mouth.

Fig. 90. High salt marsh on Hatteras Island. *Spartina patens* and the sedge *Fimbristylis* dominate.

Fig. 91. High marsh completely dominated by black needle rush.

Fig. 92. Salt panne dominated by *Salicornia* spp. (glasswort), between high and low marsh at Codds Creek Transect 1. Pannes are created by evaporation of salt water.

Fig. 93. Upper part of a low marsh, with the short form of *Spartina alterniflora*.

often missing, particularly on marsh islands that face the prevailing winds and resulting waves which undercut and erode the edge. In such areas there is a sharp drop from the marsh surface to the sound bottom, so that roots cannot extend outward.

The luxuriantly growing marsh edges have incredible biomass values, with culms reaching 2 m or more. This type of marsh is usually found on overwash deposits; the most productive marsh we found on Core Banks was at Codd's Creek, where about 15 years ago a bay bottom was filled in by overwash, as shown in Fig. 27. The marsh substrate is definitely beach sand sloping gradually down to the bay bottom, and provides an optimal growth surface flushed by the tides. After a few years of growth, the standing crop was twice that of the older, more typical marsh nearby. Rather than destroying estuarine resources, as some alarmists have implied, overwash increased the productivity of this marsh many times and provided a superb habitat for marine animals.

Salt marshes can thus develop in several ways and achieve varying degrees of productivity. As sea level rises, salt marshes can form on what was formerly higher land, as on Shackleford Banks, where marsh grass now surrounds old stumps (Fig. 53). Secondly, salt marshes will form where overwash sediments are poured into a bay bottom and a proper slope develops. This means that older marshes are probably buried, but these are no doubt much lower in overall productivity than the marshes which grow up on the new sediment. These overwash marshes are not particularly extensive; they only grow as fringes along the back side of the island. The third, and most extensive, marshlands are formed by inlets as described above. Since most of the marshland associated with barrier islands is apparently of this type, it is obvious that the appearance and disappearance of inlets are important to estuarine productivity for the marshes they create as well as for exchange between the sounds and the sea.

If sources of sediment are available in the sound, gradually sloping edges along the salt marshes will persist and the marshes will expand. However, the marsh surface usually grows upward by accumulation of organic matter until it nearly builds itself up out of the reach of tides. The result is low productivity and short grass. Eventually, these marshes are usually covered by overwash as the island retreats. Since the marsh is growing upward and since sediment is often in short supply, the borders of most marsh islands are breaking down. Until a new inlet forms or overwash provides new sediment, these marsh edges will continue to disintegrate.

Marsh grass can readily invade new sediment brought in by overwash or the tides, either by rapid rhizome growth or by seeds. Measurements at a seawall on Core Banks near an old Coast Guard station attest to this colonization ability. In the late 1950s the station was active and had a

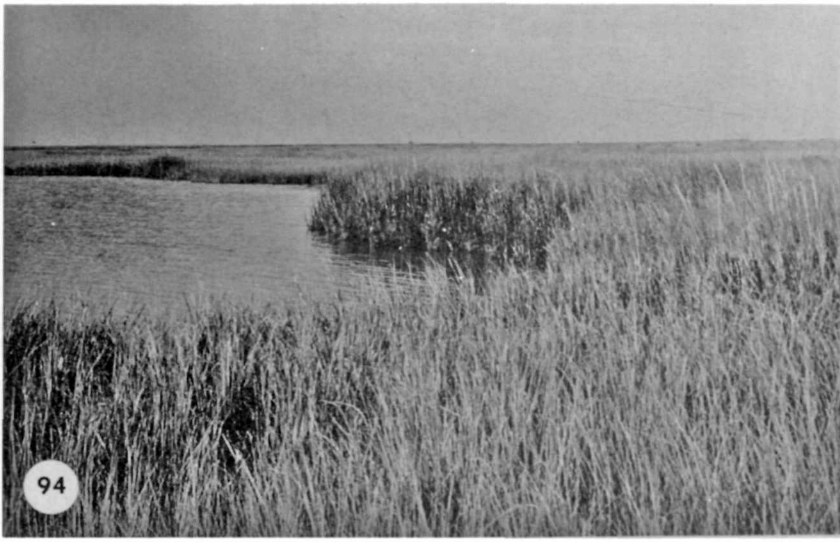


Fig. 94. Lower edge of a low marsh, with tall *Spartina alterniflora* advancing into the creek on old overwash deposits.

Fig. 95. (*A*) Experimental marsh planting at the site of the Atlantic Coast Guard Station, Core Banks. *Spartina* plants taken from adjoining marsh were planted 0.5 m apart. (*B*) The same, after one growing season; all plants have survived and are spreading vegetatively. (*C*) The same in the summer of 1971. The grass has grown until it is indistinguishable from the natural marsh. Sand washed in from the sound has been stabilized and has raised the level of the new marsh.


B


C

boat basin close to the sea wall. After the abandonment of the station, overwash provided enough sediment for a salt marsh to grow up in that basin (Fig. 23); the grass is moving into the sound at about 1 m per year. In 1969 we tested whether this grass would grow in overwash sediment, and at the same time tried transplanting the grass. A 2 × 5 m plot was planted with marsh grass; within 2 years it had a density and biomass equal to that of natural marshes nearby (Fig. 95). Transplanting marsh grass is indeed practical and of increasing interest to coastal managers.

4
Effects of Man on the Outer Banks

Human beings probably paid visits to the Outer Banks as long as the islands have existed. We know little about the activities of Indians on the Outer Banks, although Indian burial grounds have been found on Bogue Banks. It seems likely that the other islands were used as bases for fishing and shellfishing at least at certain times of the year. The Indians may have set fire to the grasslands at times, but grassland ecosystems recover quickly from a light burn; in general, the environmental impact of Indian use of the islands was probably rather minimal.

Technological man is another and sadder story. In colonial times small settlements of fishermen and especially of livestock raisers developed here and there along the Outer Banks. These people cut wood for fuel and boat building. This, combined with natural dune migration and sea-level rise, reduced the forest cover on several islands. In at least one important respect, however, the early settlers were more sensible than their modern counterparts; they built their houses in sheltered sound-side locations rather than on the edge of the ocean, and were safe from all but the most severe storms without the help of artificial dunes and dikes (Fig. 96). See Dunbar (1958) and Holland (1968) for comprehensive treatments of the human history of the Outer Banks.

Livestock was the main industry; one could turn out one's sheep, cattle, hogs, and horses on the broad acres of dune grass and salt marsh without need of fences and know that they were safe from land-based marauders. Overgrazing apparently became a problem on some of the Outer Banks and is still troublesome on parts of Shackleford. Portsmouth Island was considered severely overgrazed as early as 1810 (Dunbar 1958). Local people tell us that before the livestock was removed from Core Banks in the 1950s, the island was nearly denuded and the animals were starving. Whether such conditions were due to overgrazing or to natural processes during that time is difficult to determine. Nevertheless, grassland ecosystems of Core Banks are healthy today, illustrating how quickly the islands can recover if allowed to do

so. Portsmouth Island, which has had the longest and most severe grazing history, seems unfortunately to have been damaged beyond its natural ability to repair itself. Most of the island is a low, bare flat, awash with every high tide as were other islands on the Outer Banks (Ocracoke, Bodie) before dune-building projects were begun in the 1930s; the land-building processes of overwash and dune formation are not working here. This is the only one of the undeveloped barrier islands which might accurately be said to be "washing away." Extreme overgrazing followed by some bad storms may have been responsible for the present condition of Portsmouth. On Shackleford Banks there are still herds of sheep, goats, cows (Fig. 97), and horses, and the damage they do is evident, yet the conditions of Portsmouth have not developed here. In the dunes the herds graze selectively on *Andropogon scoparius* and also reduce the cover of *Uniola paniculata* (Fig. 98), but the worst effects are blowouts and open sand due to trampling, which can speed up dune movement (Fig. 99). In the maritime forest there is a distinct browse line on the trees—mostly due to the goats—and tree reproduction is doubtless impaired (Fig. 100). But it is in the salt marshes that grazing takes its worst toll (Fig. 101). The marshes are the main feeding ground of the island's horses, and they bite the *Spartina* down to within an inch of the mud, which must significantly reduce estuarine productivity in this locality.

The overall effects of grazing animals on the Outer Banks are difficult to assess. Some localized areas were undoubtedly overgrazed and thus livestock were blamed for the "deteriorated" condition of the entire Outer Banks. Yet, as Dunbar (1958) pointed out, the peak of grazing pressure exceeded by at least a half century the period during which the animals were blamed for this alleged destruction. Indeed, Shackleford Banks, which had extensive moving dunes at the turn of the century and was never stabilized by human activities, yet all the while was grazed, now has extensive vegetation cover over most of the island. Engels (1952) felt that the general nature of the barrier islands was due primarily to natural forces, and our research seems to support that view, although localized grazing pressure could lead to more rapid sand movement than would normally be expected.

Livestock were not the only animals introduced. With the settlers came the inevitable house mice and rats, as well as a population of feral cats. The latter doubtless do a service in controlling the rodents, but certainly prey upon the islands' many species of ground-nesting birds as well.

Finally, certain game birds and animals, such as pheasants and raccoons, have been brought to the islands for hunting, but these seem to have fitted into the island ecosystems without noticeable dislocation of the systems.

Fig. 96. Portsmouth Village was once the largest settlement on the North Carolina Outer Banks. The few buildings remaining were built a sensible distance back from the beach.

Fig. 97. Feral cattle on Shackleford Banks, remnants of once large herds.

Fig. 98. Effects of grazing on the Shackleford dunes; the square area represents an exclosure before the fencing was stolen. During a year of relief from grazing, the cover inside the fence increased significantly, particularly *Andropogon*, which is selectively grazed.

Fig. 99. The network of paths and openings among the Shackleford dunes is partly cattle and horse trails.

Fig. 100. The parklike appearance of Shackleford woods is due to browsing.

Fig. 101. Part of the Shackleford horse herd and some of the salt marsh they have grazed down to the mud. After 2 years, the standing crop of *Spartina alterniflora* inside the exclosure was 30 times that on the outside.

Plants have been introduced on the Outer Banks as well as animals. The use of *Ammophila* (whose natural range is north of Cape Hatteras) as a dune-building grass has already been mentioned. *Populus alba* (silverleaf poplar) and *Gaillardia*, a colorful composite, were brought in by the settlers as ornamentals. The poplar survives in scattered locations, especially in Portsmouth Village and villages on the Hatteras Banks, but the *Gaillardia* has spread everywhere. There is no indication that it has displaced any native species, however, and it performs a sand-binding service. Loblolly pines and some exotic species of *Pinus* were planted in the Cape Lookout area in recent years in a well-meant attempt to control sand movement. How long they will survive and how much good they will do are uncertain, but the tracks of the truck used to plant them are still visible on the grassland and may remain so for some time (Fig. 102).

Modern development of the Outer Banks has usually proceeded with unfortunate disregard for the dynamics of the environment (Fig. 103). Houses, motels, roads, and recreational facilities not only mean inevitable destruction of dunes, woodland, or salt marshes where they are built (Fig. 104), but they require engineering work for protection from the sea. The difficulties that arise from building artificial dunes and from preventing overwash and island migration have already been discussed. On privately owned sections of Bogue Banks and elsewhere along the North Carolina coast, developers have leveled the fore-dune in order to build as close to the sea as possible and have removed maritime forests to create lots for homes (Fig. 105). The inevitable result is rapidly moving sand and storm flooding on a part of the island which grass and trees took years to stabilize. In addition, exposed trees soon die from salt spray since they are no longer protected by dunes or seaward vegetation.

Despite the obvious hazards of building too close to the beach, new hotels, such as the Holiday Inn on Wrightsville Beach shown in Fig. 106, are being constructed all along the Atlantic shoreline and are inviting disaster from the next hurricane. After a short time, the beach retreats and the owners of beach property then lobby for a publicly funded beach nourishment project (Fig. 107) to protect their private holdings which, in most cases, should never have been built there in the first place. Thus starts a never-ending cycle of erosion and temporary engineering solutions for a situation that will continue to worsen.

On the western end of Bogue Banks, acres of prime maritime forest, festooned with *Tillandsia usneoides*, were cleaned off to build a four-lane highway (Fig. 108). Near the middle of the island, one developer has gone so far as to cut nearly through the dry land with a channel from the sound side to provide boat access to a trailer park, thus inviting the formation of a new inlet by the next big hurricane.

Fig. 102. A 1971 photo of Core Banks showing the tracks of the vehicle used to plant pine trees in 1969. These tracks will be here for some time.

Fig. 103. The effects of modern development on Bogue Banks; contrast with the undeveloped beach in Fig. 102.

Fig. 104. Bogue Banks at Atlantic Beach. Marshes have been dredged and bays filled for housing developments and trailer parks. All are vulnerable to a big hurricane.

Fig. 105. Dunes leveled by a developer on Bogue Banks.

Fig. 106. A resort motel under construction at Wrightsville Beach, North Carolina. The high tide line is in the foreground.

Fig. 107. The eroded scarp typical of beaches artificially built of fine sediment dredged out of the sound.

All these developments must be supplied with water. Deep wells on the islands produce water that is unpleasantly sulfurous. Shallow wells sunk into the surface water table result in better water, but the water table floats as a lens resting on and surrounded by salt water, and is derived entirely from rainfall. If too much fresh water is removed, the salt water moves in more or less permanently. This is a widespread difficulty with coastal water supplies.

That those who use the developments may be spared the problem of mosquitoes, some of the Outer Banks' salt marshes have been ditched and, in the past, sprayed. This removes a small amount of the marsh itself from estuarine productivity, and may have other ecological effects such as drying out the marsh so that more terrestrial and less productive species can invade. However, the overall result may not be entirely negative, since there are suggestions that nutrient exchange and productivity output may be improved by ditching (Fig. 109).

Marshes have also been used as a source of beach fill and barrier dike material, as well as being filled for various development purposes (Figs. 110 and 111). Such ecologically disastrous operations should presumably no longer be permitted on Federal lands, but they are still being carried out at alarming rates on private land, despite efforts to protect these resources. Dredging and filling of marshlands have been all too common activities behind the more easily accessible barrier islands. The size of Cape Lookout, however, has been greatly increased in recent years, and its shape changed, partly because of the jetty which was built there in 1915 (Figs. 129 and 130).

The effects of technology and development on barrier beaches are graphically illustrated when natural beaches are compared to highly modified ones, where erosion has become a problem and various techniques are being used to "control" barrier-island retreat. Figure 112 is an aerial view of the still undeveloped Cape Lookout beach system, where the only major human impact consists of the lighthouse and a few buildings on the back side of the Cape. Storm tides can sweep across Cape Lookout but do no real damage, and the beach retreats according to natural processes. Here beach erosion is not a problem.

In contrast, Figs. 113 and 114 show several stages in the degradation of the beach at Cape Hatteras, and consequent attempts to control erosion. The Cape Hatteras region was once much like Cape Lookout, with a wide beach and no developments near the beach. Historically, the section of the Hatteras beach near the lighthouse has experienced continuous retreat, but when the lighthouse was built in the mid-1800s, the beach was wide. Over the years the beach has retreated closer to the lighthouse. The greatest problems came in recent years, however, following the creation of a "stabilized" dune line on the beach. Private land was quickly developed with summer houses and motels, and in ad-

Fig. 108. Road cut through an outstanding maritime forest on western Bogue Banks.

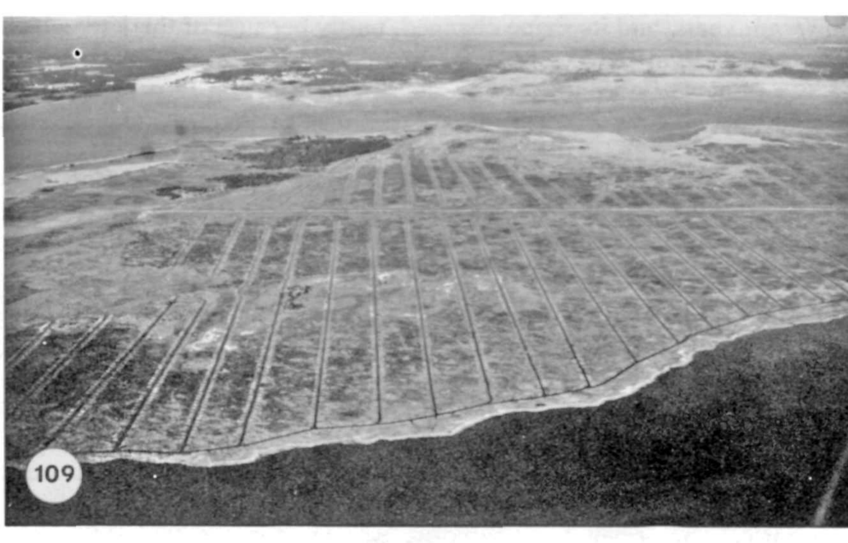


Fig. 109. Salt marsh mosquito ditches in eastern North Carolina. The ditches are 6 ft. (1.8 m) wide, very deep, and built without regard for natural drainage patterns.

Fig. 110. This boat-launching bay was made by excavating a salt marsh to get fill to shore up an eroding dune line. Cape Hatteras National Seashore is in the background. The already vulnerable island has been further narrowed.

Fig. 111. Marsh adjacent to the same bay is being filled to make a parking lot for the boat launchers. This sort of thing would presumably not be done today.

Fig. 112. Cape Lookout Lighthouse. Thirty or forty years ago the Hatteras Lighthouse was separated from the ocean by a similarly wide berm. (*Photo by* R. Simpson.)

dition, a U.S. Navy facility was built just north of the lighthouse. The man-made dunes did not solve the erosion difficulties, but they have been increasingly attacked by waves, with obvious threat to the structures behind.

As the stabilized dunes broke down, various temporary remedies were initiated, such as placing bags of sand at the toe of the dune in front of the lighthouse (Fig. 113A). Following the failure of these attempts, three groins were built opposite the naval facility and the lighthouse, resulting in predictable changes in the beach system (Fig. 113B). The groins did indeed stop migration of sand down the beach from the north and widened the beach, but the downdrift side of the structures was then starved for sand, and here erosion was greatly accelerated. Concern was then raised about the historic site of the former lighthouse, south of the present structure, which was soon threatened by more rapid erosion, not to mention the general loss of National Seashore land south of the groins. Thus, while the groins may have slowed the erosion at the lighthouse, they hastened the loss farther down the beach and changed the whole shape of the shoreline.

With erosion continuing to the north of the lighthouse (which soon took on the appearance and exposure of a headland at sea), and periods of overwash through what remained of the dune into the developed areas (Figs. 114A and 114B), a plan was devised to artificially restore the beach. Sand was pumped from an accreting part of Cape Hatteras south of the lighthouse to the eroding sections on the north side (Fig. 114C).

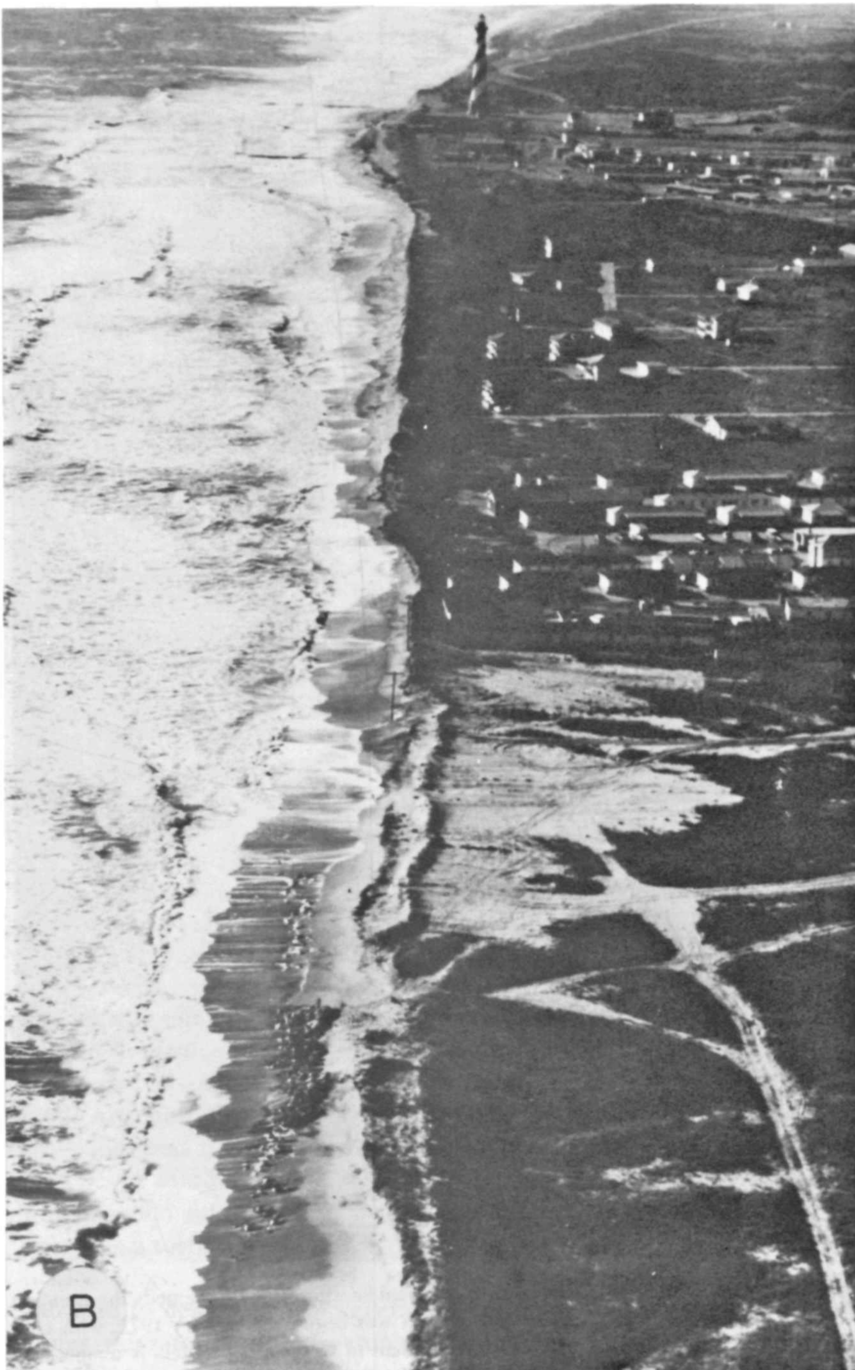
This beach "restoration" is another type of environmental tampering which has both positive and negative aspects. Dredging fine sediment out of the estuaries and marshes to "nourish" the beach is purest folly, for the material is so fine that it is soon washed away in the high energy environment of the beach (Fig. 107). The beach is "improved" for only a little while, but the sound or marsh from which the fill was taken is damaged permanently. Clearly, the short-term benefits obtained by this operation must be weighed against the longer-term costs of estuarine destruction. Nourishment can be more useful when normal beach sand is moved from accreting to eroding areas, thus putting the sand back into the littoral drift (Fig. 114) or by pumping spoil from inlet dredging onto the downdrift beach. All such operations are expensive in terms of initial costs, long-term cost, and hidden ecological cost. They are clearly only temporary solutions, and must be carefully evaluated as to the value of the structures they are designed to protect. In many cases it might be cheaper and more desirable to remove or relocate the threatened buildings than to continuously rebuild the beach by artificial techniques.

The most practical "use" that can be made of the Outer Banks is

Fig. 113. (*A*) In 1969, Cape Hatteras Lighthouse and the naval facility just beyond were in serious danger from the sea. The white strip in front of the lighthouse is plastic bags filled with sand. Note the narrowness of the beach, the irregularity of its outer edge, and the artificial dunes in the foreground. (*Photo by* Cape Hatteras National Seashore.) (*B*) The ►

beach after groins were built in 1970. The groins have captured sand moving down the beach and the lighthouse is temporarily safe, but note how the artificial dune has been cut away by erosion on the downdrift side of the groin. (*Photo by* Cape Hatteras National Seashore.)

Fig. 114. (*A*) Looking south along the Hatteras Island beach in 1969. Note motels and private houses just behind the dune line. (*Photo by* Cape Hatteras National Seashore.) (*B*) The same just after a bad storm in November 1971, cut away much of the dune line. There has been a breakthrough with overwash; the waves are very close to the motels; the objects on the beach in the foreground are the remains of plastic bags filled with sand to ➤


B

hold back the sea. (*Photo by* Cape Hatteras National Seashore.) (*C*) To remedy the situation in *B*, an experimental beach nourishment project was begun in February 1972, with sand pumped from Hatteras Point. The erosion problem in front of the motels is temporarily relieved. (*Photo by* Cape Hatteras National Seashore.)

recreation. A great deal of fishing, shellfishing, hunting, swimming, and just plain enjoying the outdoors has taken place on both developed and undeveloped islands over the years. There is nothing intrinsically destructive to the environment about these activities as long as the participants follow the rules on catch limits, and if they can enjoy themselves without the help of a lot of environmentally destructive development. Unfortunately, a good many people have shown no respect for the Outer Banks environment and have spoiled a great deal of it for more sensitive visitors. Surf fishing on Core Banks is a case in point. There are a great many camps on the island where the fishermen stay; clusters of them are sometimes surrounded by rings of abandoned cars towed there in an effort to protect the buildings from the sea (Fig. 115). Fishermen bring to the island an old car which they drive up and down the beach until it wears out or gets hopelessly stuck. This in itself does no real harm unless the car is driven over dune grass or through bird nesting grounds, but the car is eventually left to rust on the beach, where it is an esthetic insult and a safety hazard. No one wants to pay to have a valueless vehicle ferried ashore. There are probably over a thousand such hulks on Core Banks (Fig. 116). Most builders of cabins are squatting on the land, since at present most of the land in Cape Lookout National Seashore is owned by the state of North Carolina. Although some people have put up neat, decent little buildings, many of the cabins are unsightly, vermin-infested hovels surrounded by rubbish (Figs. 117 and 118). Such conditions will eventually be remedied by the National Park Service as it takes control of Cape Lookout National Seashore. (Esthetics and health considerations aside, the cabins do show that it is possible to build on the unprotected parts of the islands if one accepts flooding as inevitable; the camps are built mostly on posts and the high water simply flows underneath.)

The use of vehicles on the Outer Banks has other environmental consequences. One is positive: the tracks on the beach often catch windblown seeds and start long double lines of *Uniola paniculata* and *Spartina patens*, some of which may become dunes (Fig. 119). The seeds of *Uniola*, in particular, require burial before they can germinate (Wagner 1964) and when blown into the tracks are soon covered over by drifting sand. Another effect is not so desirable. Sand roads cut deeply into the grassland, and if they lead from the beach straight back to the sound, they serve as channels for excessive overwash (Fig. 120). High water which would otherwise have spread out harmlessly over the grassland becomes a torrent in the channel and sometimes badly erodes the island surface (Figs. 121 and 122). Uncontrolled vehicular use in dune areas can lead to destruction of vegetation and increase the rate at which the dunes migrate. Running vehicles on the beach can play havoc with shorebirds and other organisms that depend on the beach system for

Fig. 115. A typical fishing camp on Core Banks, with a line of old cars in front to catch sand.

Fig. 116. The cars have started a few small *Uniola* dunes, but the unsightly array does not help the beach nor does it provide real protection from a major storm.

Fig. 117. A representative scene inside the fishing camp.

Fig. 118. Solid waste and the remains of a feral cat on Core Banks.

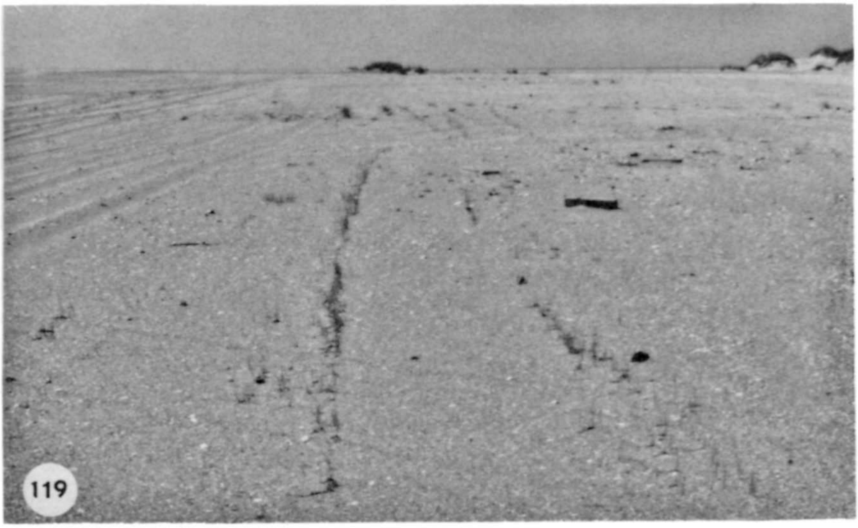


Fig. 119. Young *Uniola* plants from seeds trapped in car tracks.

Fig. 120. This road running at right angles to the Core Banks beach became an overwash channel during Hurricane Doria in 1971.

their livelihood. Heavily used beaches have few nesting shorebirds since the birds require a certain degree of solitude to raise young. Where vehicles constantly churn up the sand, there may also be significant changes in the functioning of the beach ecosystem, which includes innumerable, minute interstitial organisms as described earlier. We note that ghost crabs are commonly seen foraging in the daytime on the relatively wild beaches of Cape Lookout National Seashore, while doing so only at night on Bogue Banks and Cape Hatteras. Such behavioral differences may be the result of human interference.

Solid waste is a problem on all the islands. The attitude of many visitors toward pop bottles and beer cans is "the sea will take care of it," and heaps of nonbiodegradable containers are left wherever they are emptied. Even if visitors would properly dispose of their rubbish, every drift line on the islands contains quantities of trash washed up with the dead eelgrass and *Spartina*. Some of this has been thrown overboard from boats, which are hard to police. More comes from dumps on the mainland. Salt marshes are a favorite site for rubbish disposal, and a high tide floats the trash out into the sounds and distributes it along the Outer Banks. If the Cape Lookout islands are to be kept safe and presentable, the National Park Service will have to employ crews to pick up trash for the foreseeable future.

Various permanent installations on the islands have been sources of solid waste. The more remote outposts simply dumped trash among the sand dunes, whence it was scattered about by every overwash. Noticeable pollution has also resulted from careless disposal of waste lubricating oil. In addition, oil pollution from ships at sea is becoming a problem of increasing concern. On numerous occasions we have found oiled sea birds dying on the beach and nearly every walk along the beaches turns up globs of solidified oil. If offshore oil production in this region becomes a reality, the hazards of pollution on the Outer Banks will be greatly increased.

Dredging to improve navigation in the sounds generally serves a useful purpose, although if a new channel is dug parallel to the back side of the islands and close to the marsh edge, new marsh growth into the sound is stopped and marsh erosion is encouraged. Another apparent difficulty with channel dredging is illustrated in Barden Inlet, which opened in 1933 and has been dredged ever since. The navigation channel is aimed directly at the back side of Core Banks, following the natural deep-water channel which is migrating into Core Banks, and thence out to the mouth of the inlet. Due to the natural tendency of flowing water to meander, outgoing tides are tearing away the island behind the lighthouse and the dredging probably exacerbates this problem (Fig. 123). Cape Lookout Lighthouse (Fig. 124) is perhaps in more danger of falling into the water from the sound side than from the ocean side, as the channel keeps moving toward the lighthouse at a rate of about 20 ft (6 m) per

Fig. 121. The same road, with downcutting by the channelized overwash.

Fig. 122. The other end of the road. The water broke through a dune line and pushed sand into Barden Inlet.

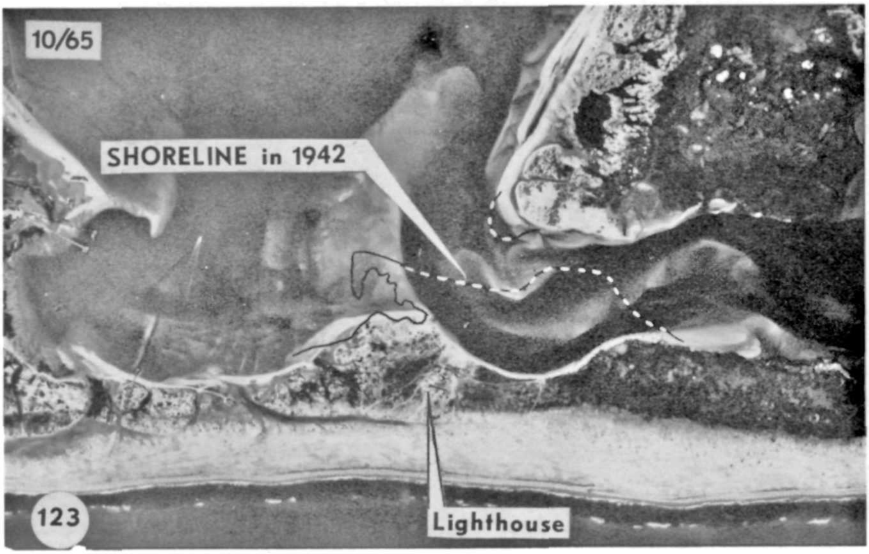


Fig. 123. Barden Inlet, October 1965, with a dredged channel aimed at the lighthouse. Superimposed is the 1942 shoreline.

Fig. 124. The resultant eroding shore of Barden Inlet.

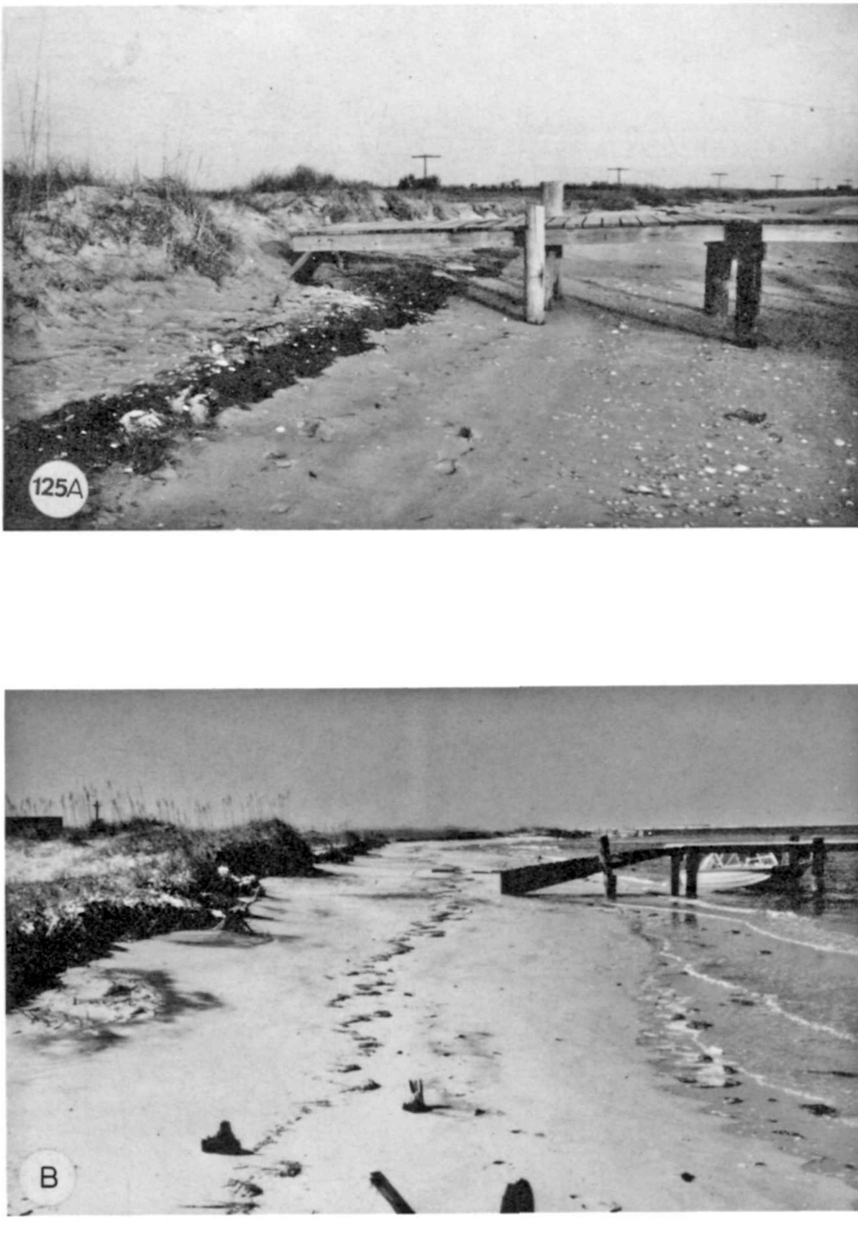


Fig. 125. (*A*) The land end of the dock in the preceding figure, 1970. (*B*) The same in 1971, with considerable further erosion.

Fig. 126. A dredging operation in Carteret County, filling part of the estuary and making the rest turbid.

Fig. 127. The Harker's Island-to-Cape Lookout channel. The spoil islands flanking it are important bird rookeries.

Fig. 128. (*A*) In 1970, the island being created in Fig. 126 was experimentally planted with *Spartina alterniflora* by scientists from North Carolina State University and the National Park Service. (*B*) The same in 1971, showing the successful growth of the grass.

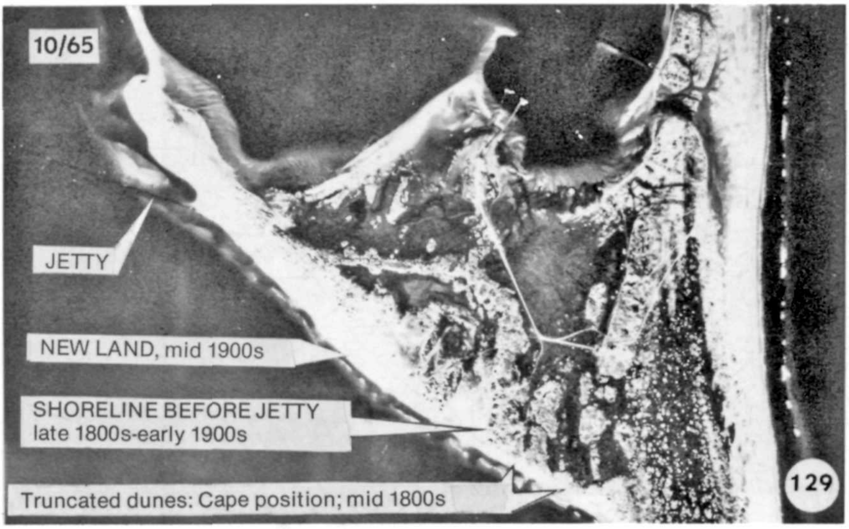


Fig. 129. Cape Lookout in 1965. The Cape owes its present shape largely to the jetty built in 1915; the former outline is shown by the large dunes visible in the photograph.

year, clearly an untenable situation (Fig. 125).

Any type of dredging increases the turbidity of the water, cutting down photosynthesis and giving filter-feeding invertebrates more silt load with which to cope (Fig. 126). In the past, dredge spoil has often been dumped on the nearest salt marsh, obviously a bad practice ecologically, but recently more constructive uses for it have been found. Spoil that was made into small islands, which now have low dunes and vegetation, is being used as rookeries by gulls, terns, skimmers, and herons in the Barden Inlet area (Fig. 127). Many similar spoil islands are becoming important rookeries as former beach habitat on the Outer Banks is disturbed, modified, or destroyed by human activities. If spoil is spread out at the correct intertidal elevation, it may be planted with *Spartina alterniflora* and will speedily become healthy salt marsh. This has been done successfully in The Straits behind Harker's Island (Fig. 128).

One positive aspect of man's presence on the islands has been the new habitat created by jetties and docks. The rocks and pilings are a solid substrate for numerous interesting marine creatures which require it and which would otherwise be very rare in North Carolina waters (Figs. 129-132). The fishing is good in these places, and educational field trips and scientific researchers make continuous use of them. The organisms on jetties and pilings need only to be protected from overly predatory SCUBA divers.

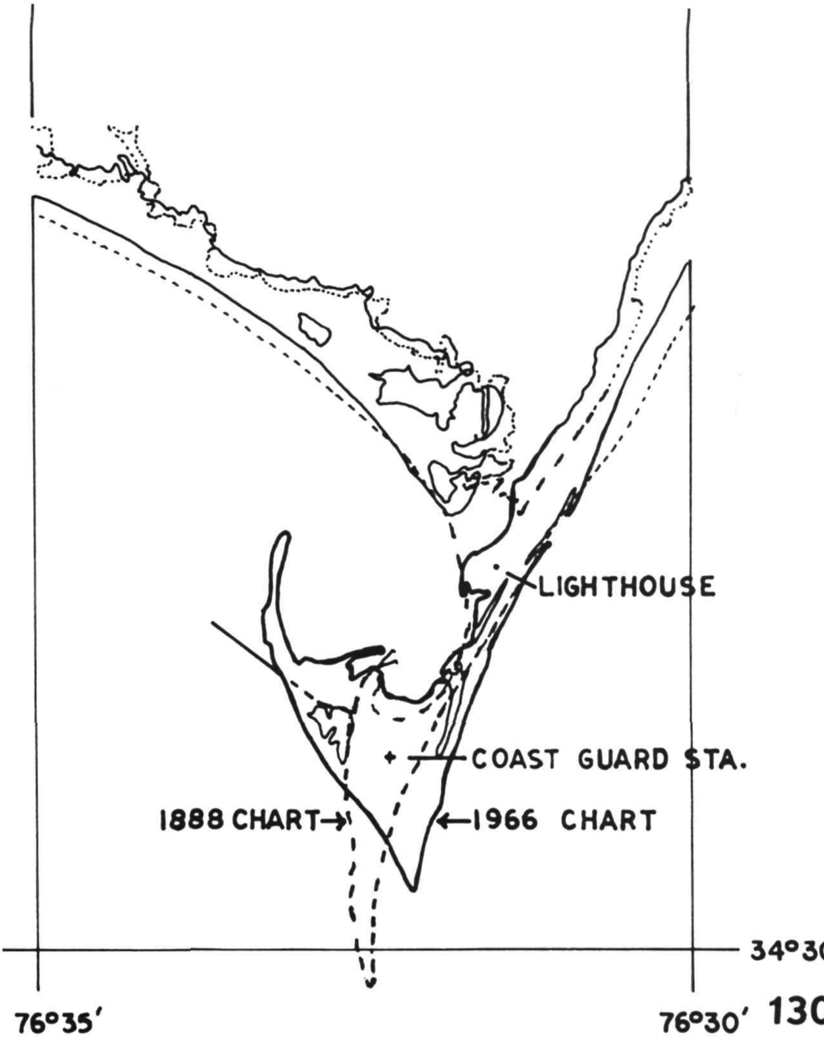


Fig. 130. Charts from 1888 and 1965 show the changes in the shape and orientation of Cape Lookout. Compare with Fig. 129.

Fig. 131. Like other jetties in the area, this one on the sound side of Shackleford Banks harbors plant and animal communities which delight marine biologists.

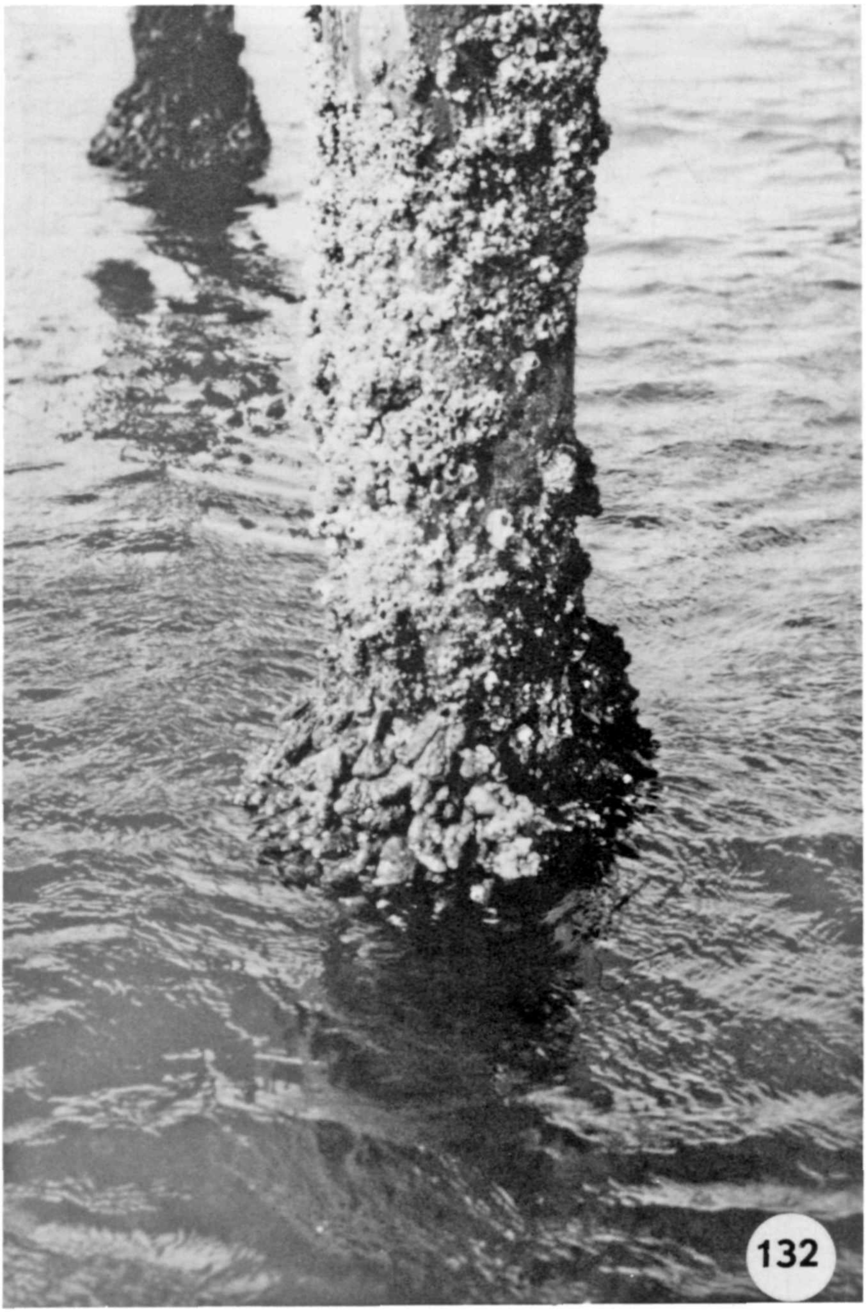


Fig. 132. A sessile community on a piling near Cape Lookout is dominated by barnacles (*Balanus amphitrite*) and tunicates (*Styela plicata*).

5 Management Suggestions

Finally, some general suggestions for the management of barrier islands as recreational areas are in order. Much of what will be said here has already been incorporated into the Master Plan for Cape Lookout National Seashore (Fig. 133), where we hope it will help National Park Service Managers avoid the difficulties with which the Superintendents of more developed seashores are saddled (Fig. 134).

The main point is not to try to fight the dynamic nature of barrier-island systems but to accept the fact that the sea level will go on rising and the islands will continue to roll back, eroding here and accreting there. These islands are no place for permanent, expensive structures, which instead belong on the mainland. Anything built on the islands should be in a sheltered, accreting area or up on pilings or both, and in any case should be simple, cheap, and expendable, and possibly movable. The only roads should be sand roads, and these should be planned so that they do not become overwash channels.

The natural stability of some islands has already been destroyed; for example, Portsmouth Island is a low, bare flat which overwash erodes rather than builds up. In such cases a program of grass-planting could help a great deal. *Spartina alterniflora* would be appropriate where the bare flats are intertidal, and *S. patens* and *Uniola* on higher ground. New dunes should be built not in a solid line but scattered so that overwash water may flow between. It would be best to use native grasses and allow natural succession to take place, so that fertilizing and insect control will not be needed.

Returning artificially stabilized sections of National Seashores, such as Cape Hatteras, where long lines of vulnerable barrier dunes have been built, to the natural flexibility of wild barrier islands may be more difficult and is certainly more controversial. However, such a policy is feasible along certain undeveloped sections where the highway is far from the beach. In these areas, natural breaks through the dunes can be tolerated. Once overwash occurs, there need not be an immediate rush

Fig. 133. Black skimmers taking off from a spoil island rookery beside the Cape Lookout channel. Marine birds are among the many plants and animals that are part of the wild and increasingly valuable natural barrier island system that is Cape Lookout National Seashore.

to fill the gap artificially. Instead, allow natural revegetation of the overwash fan or, if necessary, plant grasses on the overwash deposit so there will be vegetation and small dunes to slow down the next storm surge. The basic philosophy is to allow a natural, irregular dune line with overwash passes to develop. This is not to suggest that the practice of maintaining dunes be abandoned entirely, but rather that it be modified to follow natural patterns.

On some islands there is already expensive or historically interesting development which it is considered necessary to protect. It is hard to make recommendations for protection which will not lead to more trouble in the long run, and one should consider carefully whether the expense of protection is really justified. If beach nourishment is considered necessary—and it should be avoided as much as possible—the sand should be taken from an accreting section of the beach itself, not from the sounds; nourishment will be a short-term solution at best. Sea walls, etc., can be built if one is willing to spend the money, but if an isolated location is thus reinforced and the rest of the system is allowed to retreat naturally, the final result will be a fortified island at sea, with the rest of the barrier migrating away. In some cases it might be cheaper just to move everything back away from the beach. Paved roads, where we must have them, will simply have to be cleared of sand when neces-

sary, and eventually moved back along with the buildings. Groins are too often a snare and a delusion and should be avoided unless one is quite sure what their effect will be and that it will be useful.

The importance of inlets to the maintenance of the islands and sounds has been mentioned; the creation of new inlets for navigation may be quite acceptable ecologically. The sand removed, however, should be added to the littoral drift or should be spread out at the right level in back of the islands and planted with *Spartina alterniflora*, such as was done when the U.S. Army Corps of Engineers opened the new Drum Inlet in 1971. This latter is also the best thing to do with spoil from dredging channels; to put such fine-grained material on the beach is to waste it.

Livestock and other undesirable feral animals should be removed from the islands where they remain. If feral horses are considered esthetically desirable, the size of the herd should be kept well within the carrying capacity of the land.

Recreation on the barrier islands will have to be compatible with the island environment; trying to make the islands meet all desired uses will destroy the resource. It also should be recognized that not all types of recreation can be pursued at the same time in any given place. For instance, there are those who would be angered if not allowed to use the barrier beaches solely as a highway for beach buggies. On the other hand are those who cannot be happy except on a pristine strand devoid of any evidence of man, even their fellow purists. Surf fishing, swimming, and surfing are all healthy outdoor sports, but they cannot be safely combined on the same beach. Perhaps different times and places should be allocated to different groups of users, the philosophy being "each to his own within the limits of the environment."

Off-road vehicles are often damaging to barrier island ecosystems and their use should be closely supervised on the islands. There should be requirements that all vehicles taken out to the islands must be returned. Bridgeless, roadless islands should be kept that way, and some system of public ferries and over-sand transportation should be devised to transport visitors with minimum ecological impact. All vehicles, public or private, should be strictly limited as to where they may be driven and should be prohibited from bird rookeries and feeding areas, as well as from beach vegetation.

The abandoned cars already on the islands, the shacks, and as much solid waste as practical should be removed, which will be quite an undertaking. Perhaps a program of public education would encourage people to be more careful on the islands and to locate mainland dumps out of reach of high tide.

Camping on the Outer Banks will present problems during insect season, which is nearly any time but winter. To help relieve pressure for

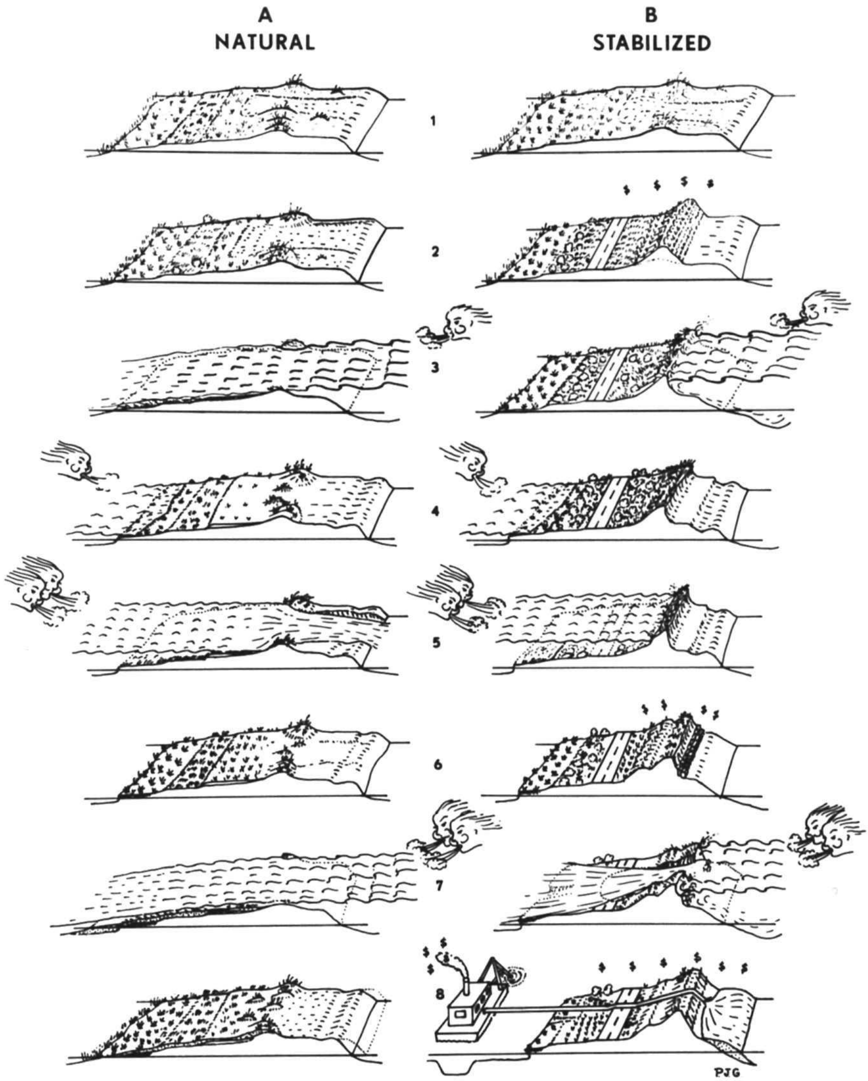

A
NATURAL
B
STABILIZED
1
2
3
4
5
6
7
8
PJG

Fig. 134. Schematic responses of natural and stabilized barrier islands to storms.

1. Both A and B are essentially alike at the start. Both have a wide berm, low, open dune system, grasslands, and can be overwashed.

2. In B, money has been spent to build a road and a dune to protect it; the island has been "stabilized."

3. A moderate storm strikes both islands and overwashes A. B cannot be overwashed because of the continuous dune, but there is severe erosion of both beach and dune. The erosion narrows the beach and creates deeper water nearshore, which causes more wave damage to the dune. In B there is little or no dune erosion although the beach has retreated.

4. Following the storm, the overwash terrace in A has become vegetated, and new dunes are forming. No damage can be seen. However, in B, the stabilized dune is badly eroded, and the berm markedly narrower. A new beach has been formed on both islands by gentler waves following the storm. Note that shrub vegetation has increased along the road and behind the dune in B. Strong winds from the lagoon side of the island are creating waves in the lagoon, which erode the edges of the salt marsh.

5. A severe storm with winds blowing across the lagoon has flooded the backshore of both islands. In A these flood waters can flow out to sea across the island. In B they are trapped by the man-made dune, and flood the road and other facilities. In A the flood waters remain shallow on the island and last for only a short time. In B they become deep and stand on the land for a long time. Some dune erosion may result on the backside of the dune.

6. The effects of the storm are not evident on the natural island. All vegetation zones are alive and healthy, although the edge of the salt marsh has eroded more. In B, repair work is being done to the back of the dune line. The marsh edge also has eroded. Plants not tolerant of long-term flooding have died. Further attempts to protect the main dune line have been started, with bags of sand being placed along the eroding base of the dune. The problems in B have resulted in major expenses.

7. A severe storm strikes the islands, with different effects on the two islands. In A a sheet of water sweeps completely across the barrier, carrying sand onto the backshore and into the lagoon. A relatively uniform overwash layer has been spread over the island; the beach has retreated. In B, however, the storm resulted in massive erosion of the beach and dune line. The storm waves piled up against the dune-dike and finally broke over the top. The resulting torrent severely damaged the rear of the dune, buried the road deep in sand, and eroded the back of the island as it swept across.

8. Following the storm, the islands are very different. In A, all signs of the storm are gone. All vegetative zones have redeveloped on the overwash layer, including a new salt marsh. New dunes are forming on the beach. The main change is a slight retreat of the barrier. In B, massive projects, at great cost, are underway to rebuild the barrier in the same place. A beach nourishment project is pumping sand from behind the barrier to rebuild the beach and the dune. (Such lagoon-side dredging operations for fill are no longer carried out on National Park Service land because of the ecological damage to the lagoon and the generally poor quality of the sediment. Recent nourishment sources have been accreting spits or inlets.) Once the dune has been built, it will be grassed. Even though the beach has been temporarily restored, the next storm will create difficulties again. Because of the lack of overwash sand, there has been no backshore elevation increase nor any sediment for new marshes in the lagoon. The edge of the marshes continues to erode. More and more effort will be needed to maintain B, while A will continue its natural cycle in equilibrium with the oceanic forces.

spraying programs, which we consider ecologically unacceptable, camping areas should be located where the prevailing winds will tend to blow away the insects, and visitors should be warned of the situation.

Finally, and perhaps most importantly, while we allocate pieces of the islands to various purposes, we should not forget to set aside substantial areas as wilderness. The most representative and undamaged examples of each habitat type should be included. Such a plan is perfectly compatible with the Recreation Area concept when we consider that wilderness sections will be available for comparison with the parts of the islands we are using. Thus we can determine whether we are damaging either the recreational resources or the general health of all the various ecosystems associated with barrier islands.

References

AU, SHU-FUN. 1969. Vegetation and Ecological Processes on Shackleford Bank, North Carolina. Ph.D. Dissertation, Duke Univ. 170 p.

BOYCE, S. G. 1954. The salt spray community. *Ecol. Monogr.* **24**:29–67.

BURKE, C. J. 1962. The North Carolina Outer Banks: a floristic interpretation. *J. Elisha Mitchell Sci. Soc.* **78**:21–28.

CARNEY, C. B., and A. V. HARDY. 1967. North Carolina Hurricanes. Environ. Science Serv. Admn., U.S. Dept. of Commerce, Weather Bureau. 40 p.

CHAPMAN, V. J. 1960. Salt Marshes and Salt Deserts of the World. Interscience Publishers, New York. 392 p.

CRY, G. W. 1965. Tropical Cyclones of the North Atlantic Ocean. Tech. Paper No. 55. U.S. Dept. of Commerce, Weather Bureau. 39 p.

DOLAN, R., and J. C. FERM. 1968. Crescentic landforms along the Atlantic Coast of the United States. *Science* **161**:710.

DOLAN, R. In press. Barrier dune systems along the Outer Banks of North Carolina: A reappraisal.

DOLAN, R., and P. J. GODFREY. In press. Effects of Hurricane Ginger on the Barrier Islands of North Carolina.

DUNBAR, G. S. 1958. Historical Geography of the North Carolina Outer Banks. Louisiana State University Studies, Coastal Studies Series No. 3. Louisiana State University Press, Baton Rouge. 234 p.

ENGELS, W. L. 1952. Vertebrate fauna of North Carolina coastal islands. II. Shackleford Banks. *Am. Midl. Nat.* **47**:702–742.

FISHER, J. J. 1962. Geomorphic Expression of Former Inlets along the Outer Banks of North Carolina. M.A. Thesis. University of North Carolina, Chapel Hill. 120 p.

FISHER, J. J. 1967. Relict Beach Ridges of the Outer Banks, North Carolina. Ph.D. Dissertation. University of North Carolina. 250 p.

GODFREY, P. J. 1970. Oceanic Overwash and its Ecological Implications on the Outer Banks of North Carolina. U.S. Dept. of the Interior, National Park Service. 37 p.

HICKS, S. D. 1971. As the oceans rise. *NOAA Week* **2**(2):22–24.

HOLLAND, F. R. 1968. A Survey History of Cape Lookout National Seashore. U.S. Dept. of the Interior, National Park Service. 62 p.

HOYT, J. H. 1967. Barrier island formation. *Geol. Soc. Am. Bull.* **78**:1125–1136.

HOYT, J. H., and V. J. HENRY, Jr. 1971. Origin of capes and shoals along the southeastern coast of the U.S. *Geol. Soc. Am. Bull.* **82**:59–66.

JOHNSON, D. W. 1919. Shore Processes and Shoreline Development. John Wiley & Sons, New York.

LEWIS, I. F. 1917. The Vegetation of Shackleford Bank. N.C. Geol. and Economic Survey, Econ. Paper No. 46.

MILLIMAN, J. D., and K. O. EMERY. 1968. Sea levels during the past 35,000 years. *Science* **162**:1121–1123.

OOSTING, H. J. 1954. Ecological processes and vegetation of the maritime strand in the southeastern United States. *Bot. Rev.* **20**:226–262.

OOSTING, H. J., and W. D. BILLINGS. 1942. Factors affecting vegetational zonation on coastal dunes. *Ecology* **23**:131–142.

PIERCE, J. W. 1964. Recent and Geologic History of the Core Banks Region, North Carolina. Ph.D. Dissertation. University of Kansas. 115 p.

PIERCE, J. W., and D. J. COLQUHOUN. 1970. Configuration of the Holocene primary barrier chain, Outer Banks, North Carolina. *Southeast. Geol.* **11**:231–236.

REDFIELD, A. C. 1965. Ontogeny of a salt marsh estuary. *Science* **147**:50–55.

SAVAGE, R. P., and W. W. WOODHOUSE, JR. 1968. Creation and stabilization of coastal barrier dunes. Proc. 11th Conf. on Coastal Engineering, London. Am. Soc. Civil Engr. Pub.

SCHWARTZ, M. L. 1971. The multiple causality of barrier islands. *J. Geol.* **79**:91–94.

SENECA, E. D. 1969. Germination response to temperature and salinity of four dune grasses from the Outer Banks of North Carolina. *Ecology* **50**:45–52.

SHEPARD, F. P. 1963. Submarine Geology. 2nd ed. Harper & Row, New York. 557 p.

U.S. ARMY CORPS OF ENGINEERS. 1964. Ocracoke Inlet to Beaufort Inlet, North Carolina. Combined Hurricane Survey Interim Report—Ocracoke Inlet to Beaufort Inlet, and Beach Erosion Report on Cooperative Study of Ocracoke Inlet to Cape Lookout. U.S. Army Engineers District, Wilmington, N.C.

U.S. ARMY CORPS OF ENGINEERS. 1971. Report on the National Shoreline Study. Washington, D.C. 59 p.

WAGNER, R. H. 1964. The ecology of *Uniola paniculata* L. in the dune-strand habitat of N.C. *Ecol. Monogr.* **34**:79–96.

WELLS, B. W. 1939. A new forest climax: the salt-spray climax of Smith Island, North Carolina. *Bull. Torrey Bot. Club* **66**:629–634.

WOODHOUSE, W. W., JR., and R. E. HANES. 1967. Dune Stabilization with Vegetation on the Outer Banks of North Carolina. U.S. Army Coastal Engr. Res. Center Tech. Memo. No. 22.

Index

☆ U.S. GOVERNMENT PRINTING OFFICE : 1977 O—229-995

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

NATIONAL PARK SERVICE
DEPARTMENT OF THE INTERIOR